DOCUMENT RESUME

ED 244 147	CE 038 998

TITLE	Computerized Manufacturing Automation: Employment, Education, and the Workplace.
INSTITUTION	Congress of the U.S., Washington, D.C. Office of Technology Assessment.
REPORT NO	OTA-CIT-235
PUB DATE	Apr 84
NOTE	483p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF02/PC20 Plus Postage.
DESCRIPTORS	*Automation; *Computer Oriented Programs; Computers; *Educational Needs; Employment Opportunities; Federal Government; Foreign Countries; *Futures (of Society); Industrial Education; Job Development; *Manufacturing; Postsecondary Education; Public Policy; Research and Development; Robotics; Secondary Education; *Work Environment
IDENTIFIERS	Computer Assisted Design; Computer Assisted Management; *Computer Assisted Manufacturing

ABSTRACT

This report describes the technologies of programmable automation (PA) in manufacturing, their uses, and future capabilities. Following the summary and introduction, the prospects for PA are examined from several perspectives. Chapter 3 defines PA technologies, describes their developmental trends, and evaluates the potential for the integration of PA equipment into highly-automated systems. Chapter 4 examines the prospects for employment change, including the ways in which PA may influence job design and the number and mix of jobs among firms and industries. Chapter 5 describes effects on the manufacturing work environment arising from the use of PA and discusses ways in which workers are likely to be affected--physically and psychologically. Chapter 6 illuminates emerging needs for education, training, and retraining and discusses current efforts to meet those needs. Chapter 7 discusses the structure and competitive conduct of industries supplying PA goods and services. Chapter 8 describes the roles of public and private institutions conducting PA research and development. Chapter 9 enumerates effects of governments in other countries to stimulate the production and use of PA. Chapter 10 provides alternatives for Congressional action. Summaries of five case studies and an index are appended. (YLB)

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ED244147

COMPUTERIZED MANUFACTURING AUTOMATION

EMPLOYMENT, EDUCATION, AND THE WORKPLACE

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COMPUTERIZED MANUFACTURING AUTOMATION

EMPLOYMENT, EDUCATION, AND THE WORKPLACE

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CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D.C. 20510

OTA-CIT-235

APRIL 1984

Recommended Citation:

Computerized Manufacturing Automation: Employment, Education, and the Workplace (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-CIT-235, April 1984).

Library of Congress Catalog Card Number 84-601053

For sale by the Superintendent of Documents
U.S. Government Printing Office, Washington, D.C. 20402

Foreword

This assessment culminates OTA's examination of the technical, economic, and social issues surrounding the spread of programmable automation in manufacturing. Its genesis was a public workshop in 1981 on robotics that resulted in the OTA Background Paper entitled *Exploratory Workshop on the Social Implications of Robotics* (February 1982). The assessment was requested by the Joint Economic Committee, the Senate Committee on Labor and Human Resources, the Senate Committee on Commerce, Science, and Transportation, and the Subcommittee on Labor Standards of the House Committee on Education and Labor. It was endorsed by the House Committee on Science and Technology. The assessment looks not only at robots but also at related computer-based technologies for design, production, and management.

The technologies of programmable automation, their uses, and future capabilities are described in this report. The assessment goes beyond technology description to characterize the industries producing and using programmable automation and to discuss the ramifications of the technologies for industrial structure and competitive conduct. It pays special attention to three labor-related areas: the potential for employment change, effects on the work environment, and implications for education and training. Preliminary work in those areas, including conceptual discussions and background material, was published in the OTA Technical Memorandum entitled *Automation and the Workplace: Selected Labor, Education, and Training Issues* (March 1983). Since the development and sale of programmable automation have been international phenomena since at least the 1960's, comparisons between this country and others are made as far as data allow.

A wide range of sources contributed to this assessment. While OTA drew on existing literature and conferences, it also developed its own information through workshops on labor markets, programmable automation technologies, and programmable automation (producer) industries; and through informal site visits and consultations. Eighteen case studies, including 4 on the work environment and 14 on education and training programs, and a survey of education and training activities commissioned for this assessment were particularly rich sources of data. Case study material will be made available in a companion volume.

OTA is grateful for the assistance of the assessment advisory panel, workshop participants, contractors, and many others who provided advice, information, and reviews. The cooperation of individuals at case study sites, who accommodated lengthy site visits and follow-up consultations, is especially appreciated. OTA assumes full responsibility for this assessment, which does not necessarily represent the views of individual members of the advisory panel.

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Chapter 1

Summary

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Chapter 1

Summary

Computer technology offers new opportunities to enhance and streamline manufacturing processes. Many industry observers believe that computerized manufacturing automation will help troubled U.S. manufacturers become more productive and competitive. At the same time, this new wave of automation is raising concerns similar to those that accompanied the first wave of automation technology in the 1950's and 1960's. Will the new technologies put a significant number of people out of work? Will their introduction "dehumanize" the work environment for those who remain? And how can the United States best prepare its education and training system to respond to the growing use of computerized manufacturing automation?

Though manufacturing automation technologies can be applied in a wide range of industries, the focus of this report is the application of programmable automation (PA) in discrete manufacturing—the manufacture of discrete products ranging from bolts to aircraft. Most traditional metalworking industries fall in this category, although other materials (e.g., plastics, fiber composites, ceramics) are increasingly important parts of discrete manufacturing as well. Discrete manufacturing plants are often characterized by the quantity of a product which they produce, ranging from mass production of hundreds of thousands of products, to batch production of a few dozen or a few hundred, to custom production of a single item. Because of its ability to perform a variety of tasks, programmable automation is usually associated with batch production. However, it has been used extensively in mass production, and it could be useful in custom production as well.

PA tools differ from conventional automation primarily in their use of computer and communications technology. They are thus able to perform information processing as well as physical work, to be reprogramed for a variety of tasks, and to communicate directly with other computerized devices. PA is divided into three general categories: 1) computer-aided design; 2) computer-aided manufacturing (e.g., robots, computerized machine tools, flexible manufacturing systems); and 3) computer-aided techniques for management (e.g., management information systems and computer-aided planning). When used together in a system with extensive computer-based coordination, these tools are known as computer-integrated manufacturing.

Three principal themes have emerged from OTA's study:

1. **Programmable automation is an important and powerful set of tools, but it is not a panacea for problems in manufacturing.** In part because of historic U.S. strengths in manufacturing, and because the prestige of manufacturing engineering is low relative to other engineering fields, U.S. companies have devoted relatively little effort to improving manufacturing processes in the past few decades. This neglect must be remedied in order to realize the full benefits of PA. In addition to using automation, other steps that need consideration by management include redesigning products for more efficient production, minimizing inventory levels, and improving job design and labor relations.
2. **The change in national employment induced by programmable automation will not be massive in the near term (i.e., the remainder of the 1980's).** Although the rate of application is accelerating, aggregate use will still be relatively limited for the rest of this decade. Also, the capabilities of PA remain immature. Depending on macroeconomic conditions, use of automation can increase without significant growth in national unemployment. However, PA will exacerbate unemployment

problems for individuals and regions. The potential long-term impact of PA on the number and kind of jobs available is enormous, and it is essential that the Federal Government, educational institutions, and industry begin to plan with these considerations in mind.

3. **The impact of programmable automation on the work environment is one of the most significant, yet largely neglected issues.** Depending on how it is designed and used, PA can substantially change the nature and organization of the manufacturing workplace, and consequently influence levels of job satisfaction, stress, skills, and productivity. The Federal Government has traditionally had a role in workplace concerns, and could take action to help ensure that the work environment effects of PA are favorable.

Principal Findings

The Technologies

This report emphasizes five of the PA technologies. **Computer-aided design** (CAD) in its simpler forms is an electronic drawing board for draftsmen and design engineers. In its more sophisticated forms CAD is the core of computer-aided engineering, allowing engineers to analyze a design and maximize a product's performance using the computerized representation of the product.

Industrial **robots** are manipulators which can be programed to move objects along various paths. Though robots receive a great deal of popular attention, they are only a small part of the family of PA tools. **Numerically controlled (NC) machine tools** are devices that cut or form a piece of metal according to programed instructions about the desired dimensions of a part and the steps for the process. **Flexible manufacturing systems** (FMSs) combine a set of workstations (usually NC machine tools) with robots or other devices to move material between workstations, and operate under central computer control. Finally, the use of PA tools for design, manufacturing, and management in an integrated system, with maximum coordination and communication between them, is termed **computer-integrated manufacturing** (CIM).

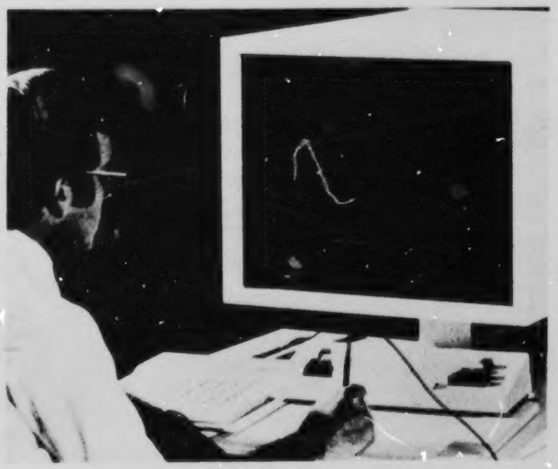

Photo credit: Cincinnati Milacron Corp.

An engineer using a computer-aided design system

The advantages of PA for management lie primarily in its ability to **facilitate information flow, coordinate factory operations, and increase efficiency and flexibility.** Further, the technologies promise an increase in management's degree of **control** over operations. The more closely tied manufacturing processes are to one another, and the more information about those processes is readily available, the less chance there is for human error or discretion to cause problems. However, this drive toward increased control can also reduce opportunities for constructive worker input and degrade the work environment.

Each of these technologies is in a relatively early stage of development, and even earlier stages of application. Robotics is well established only for spot welding, spray painting, and some materials handling uses; NC machine tools and CAD are somewhat more mature technically, although there are still many unsolved problems. FMS and CIM are very young; virtually every application is a prototype. As systems, their potential benefits and problems are much greater than those of stand-alone automation equipment. Because of their complexity, the implementation of integrated automation systems requires extensive planning and support.

Though current technology is adequate for the vast majority of near-term uses, the level of penetration of PA into possible applications is relatively low. Technical factors that tend to slow the rate of adoption of PA technologies include its complexity, the lack of standard programing languages and interfaces between PA devices, and problems in "human factors" (essentially, the system's ease of use). A wide variety of nontechnical factors also affect the use of PA, including the availability of capital and know-how, organizational resistance to change, and the availability of appropriate education and training programs.

For various reasons, most manufacturers choose to apply automation in a stepwise fashion, beginning perhaps with one or a small number of robots, CAD terminals, or NC machine tools. Though in many cases these "islands of automation" can result in productivity and quality improvements, the full benefits of PA are only realized when these devices are connected into an integrated system. Such integrated systems are more than the accumulated substitution of PA tools for human workers or for other machines; they often involve redesigning the product or streamlining the production process itself to best make use of PA. Because an integrated system can produce more products more quickly than other manufacturing schemes, manufacturers can reduce their investment in finished product and work-in-process inventories. **These and other materials savings are often more significant than labor savings in the use of programmable automation systems.**

Researchers are working to increase the versatility and power of PA tools, to enhance their capability to operate without human intervention, and to develop the ability to integrate the tools. While there has been progress in virtually all key technical areas, the problems are sufficiently numerous and complex to keep researchers busy for many years to come. **An analysis of expected trends in the technologies indicates, however, that many important technical advances in programmable automation are expected in the 1990's** (see table 1).

Though there is much discussion of "unmanned factories," experts differ about whether the removal of virtually all humans from the manufacturing process is necessary or desirable. Some express concern that manufacturers will be preoccupied with removing humans from the factory floor at the expense of more practical and cost-effective improvements in manufacturing processes. In any case, each factory has peculiar characteristics which call for different levels of automation. For some factories it has been possible to run machine tools at night with only one person in a control room. **For at least the next 10 to 15 years, discrete manufacturing factories operating without production workers (i.e., with only a few managers, designers, and troubleshooters) will be only a remote possibility.**

Employment Effects

Programmable automation is not likely to generate significant net national unemployment in the near term, but its use may exacerbate regional unemployment problems, especially in the East North Central and Middle Atlantic areas where metalworking industries are concentrated.

The level of automation in manufacturing is one of many factors that influence industrial employment. In particular, **it should be recognized that employment in an industry is a strong function of the volume of production.** Technol-

Table 1.—Programmable Automation: Selected Projections for Solution of Key Problems
(excerpts from tables 11-15—of full report)

	Current (1984)	1985-86	1987-90	1991-2000	2001 and beyond
1) Low-cost, powerful microcomputer-based workstations for:[a]					
a) electronics design	▲	●	■		
b) mechanical design		▲	●	■	
2) 3-D vision in structured environments which have been planned to simplify the vision task	▲ ●		■		
3) 3-D vision in unstructured complex environments which have not been planned to simplify the vision task			▲	●	■
4) FMS for:[b]					
a) cylindrical parts production	▲ ●			■	
b) sheet metal parts production	▲ ●			■	
c) 3-D mechanical assembly	▲			● ■	
d) electronics assembly	▲ ●		■		
5) Standardization of interfaces between wide range of computerized devices in an integrated factory			▲	●	■
6) Computerized factories which could run on a day-to-day basis with only a few people in management, design functions					▲

[a] Microcomputer-based workstations for CAD are now being marketed, but in the judgment of technical experts consulted by OTA, they are either not powerful enough and/or not inexpensive enough to be useful in a wide variety of applications.

[b] Almost all FMSs currently running are used to machine prismatic parts (e.g., engine blocks), which are those whose outer shape consists primarily of flat surfaces. The projections in this entry refer to FMS for quite different applications: a) machining of cylindrical parts, such as rotors and driveshafts (or "parts of rotation," in machining jargon, since they are generally made on lathes); b) stamping and bending of sheet metal parts, such as car body panels; c) assembly (as opposed to fabrication of individual parts) of three-dimensional products, such as motors; and d) assembly of electronic devices, such as circuit boards. While machines currently exist for automatic insertion of electronic parts into circuit boards, an electronics FMS would integrate the insertion devices with soldering and testing equipment.

▲ = solution in laboratories.
● = first commercial applications.
■ = solution widely and easily available (requiring minimal custom engineering for each application).

SOURCE: OTA analysis and compilation of data from technology experts.

ogy is a secondary influence that governs the mix of people, equipment, and materials needed to produce a given amount of product. Hence, although PA is labor-saving, the aggregate number of jobs in an economy must be examined in the context of overall economic conditions. These conditions include short-term business cycles as well as long-term shifts in the strengths and structures of different industries, plus levels of imports and exports. Thus, the favorable effects of PA on industrial competitiveness may help to increase demand for labor or help to avert job losses that could occur in its absence.

Evaluating the employment effects of PA poses serious analytical problems. There are shortcomings in current approaches for this analysis, and **data available support only inferences as to the general directions of likely occupational and industry employment change.**

Employment change will depend on a series of complex effects on jobs. Those effects will be realized as changes in the tasks that people will do, changes in the requirements for skill, and changes in the ways managers aggregate tasks into jobs and assign them to people trained for different occupations. The scope of change may be neither obvious nor immediate, because PA will often be accompanied by significant transformations of manufacturing organization, production processes, and/or product design. The more extensive such transformations, the broader the set of people affected by the introduction of PA, and the harder it is to attribute employment effects to PA, per se.

Change in skill requirements will often reflect a shift from manual to mental work. In many cases, PA will lower the time required for people to become proficient at a task, and it may lower the amount of judgment needed. At the same time, it may lead to a requirement for general knowledge of several tasks, broadening the mix of skills needed. For example, it is likely that PA maintenance personnel will need to know how to solve mechanical, electrical, and electronic problems rather than one class of problems alone.

The fewer the tasks comprising a job, the more likely it is that programmable automation can eliminate the need for a given job. For example, spot welders who only do spot welding, are more likely to be displaced by spot-welding robots than if they do other tasks as well. However, PA offers new potential for combining diverse tasks into jobs instead of fragmenting work into narrowly defined jobs, as has historically been associated with mechanization. It raises the prospect of a tradeoff between larger numbers of narrowly defined jobs and smaller numbers of more broadly defined jobs.

A major influence on employment is the supply of labor, which will grow more slowly during the next decade or so, in large part because of slower growth of the population and an increase in the average age. The supply of younger workers will decline, diminishing competition for entry-level jobs, while the proportion and number of prime-age workers (25 to 54 years) will grow.

From early indications, it appears that PA will cause the following broad, long-term trends in occupations:

- **demand for engineers and computer scientists, technicians, and mechanics, repairers, and installers on the whole will rise**—although specific occupations (e.g., drafters) will face diminishing opportunities;
- **demand for craftworkers (excluding mechanics), operatives, and laborers—especially the least skilled doing the most routine work—will fall;**
- **demand for clerical personnel will fall; and**
- **demand for upper-level managers and technical sales and service personnel will rise,** although lower- and middle-management opportunities among users of PA may fall.

Table 2 lists 1980 levels of employment for occupations most likely to experience changes in demand. Taken together, these effects suggest major shifts in the occupational mix of manufacturing industries, especially metalworking. **Overall, the salaried or white-collar work force will constitute a larger proportion of manufacturing employment,** although it is not clear how much their ranks will grow in absolute terms. PA producers especially are likely to employ relatively few production personnel; their situation may signal future patterns among other firms and industries. Consequently, **there will be few opportunities for people displaced from other manufacturing industries to move into jobs among producers of automated equipment and systems.**

In many ways, the shifts in occupations will not be straightforward. Some skills may only be required temporarily, after technology has been introduced but before further automation is achieved. For example, when automated equipment is used in isolated applications, there may be many needs for programing. But, the integration of design with process planning and production systems reduces the need for programing, as does the development of standard, easy-to-use software packages. These "short-term" phenomena may persist for many years, making it hard to plan for long-term employment change.

The effects of PA on compensation patterns are ambiguous, partly because numerous other changes are occurring in the economy. Over the past decade, there appears to have been an erosion of medium-wage jobs, and clustering of jobs at both high- and low-wage levels. Analysts attribute this in part to the proliferation of low-wage service jobs, and in part to growing separation of administrative and production functions in manufacturing. PA will likely stem the latter trend by helping to integrate administrative and production activities. Other developments, such as slower growth in the labor force participation of women (who filled the bulk of the new, low-paying service jobs created in the past decade), may also serve to alter past trends.

Finally, compensation patterns will depend on the length of the average work week. Whenever it appears that there may not be enough

Table 2.—1980 Employment for All Manufacturing Industries, Selected PA-Sensitive Occupations

	Number	Percent	Long-term direction of change
Engineers	579,677	2.85	+
Electrical	173,647	0.85	+
Industrial	71,442	0.35	+
Mechanical	122,328	0.60	+
Engineering and science technicians	439,852	2.16	+
Drafters	116,423	0.57	–
NC tool programers	9,371	0.05	–
Computer programers	58,622	0.29	–
Computer systems analysts	42,404	0.21	+
Adult education teachers	5,165	0.03	+
Managers, officials, and proprietors	1,195,743	5.87	?
Clerical workers	2,297,379	11.28	–
Production clerks	139,947	0.69	–
Craft and related workers	3,768,395	18.51	–
Electricians	126,001	0.62	+
Maintenance mechanics and repairers	391,524	1.92	+
Machinists, tool and die makers	356,435	1.75	–
Inspectors and testers	538,275	2.64	–
Operatives	8,845,318	43.44	–
Assemblers	1,661,150	8.16	–
Metalworking operatives	1,470,169	7.22	–
Welders and flamecutters	400,629	1.97	–
Production painters	106,178	0.52	–
Industrial truck operators	269,105	1.32	–
Nonfarm laborers	1,576,576	7.74	–
Helpers, trades	100,752	0.49	–
Stockhandlers, order fillers	104,208	0.51	–
Work distributors	16,895	0.08	–
Conveyor operators	31,469	0.15	–

NOTE: Data pertain to wage and salary workers.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990 Alternatives," unpublished data.

jobs, or enough well-paying jobs, to occupy job-seekers, it is often proposed that average work hours be reduced to allow more people to hold jobs. However, the average work week cannot necessarily be reduced without lowering the real wages per employee.

In light of the attention given to the Japanese, who use PA extensively and who have expanded production, it is instructive to see how their work force has been affected. Japanese companies have displaced labor, but displacement has often been masked by shifting relationships between manufacturers and suppliers, and by selective layoffs that affect primarily female, middle-aged, and older personnel.

Work Environment

Application of computers to the manufacturing workplace offers a range of options for organizing work in ways that will enhance the workplace. PA, in particular, provides the potential to achieve a better balance between the economic considerations that determine technological choices and the social consequences of those choices in the workplace. Although historically U.S. manufacturers have tended to place a lower priority on work environment issues, there is a growing awareness among manufacturers that attention to the work environment ultimately has payoffs in productivity. Work environment issues may become more important to the public, meanwhile, as changing employment patterns reduce the opportunities for personnel to move out of unsatisfactory manufacturing jobs into others.

The various forms of PA have both positive and negative effects on the safety and health of workers. **The introduction of programmable automation will create new situations, or perpetuate old ones, that have negative psychological effects on the work force.** Two of the principal effects are boredom and stress. Boredom and stress in the automated workplace can result from the characteristics of the design of the technical system and work organization, as well as from such factors as lot size and the nature of the product manufactured. In sites visited for OTA work environment case studies, it was evident that both FMSs and NC

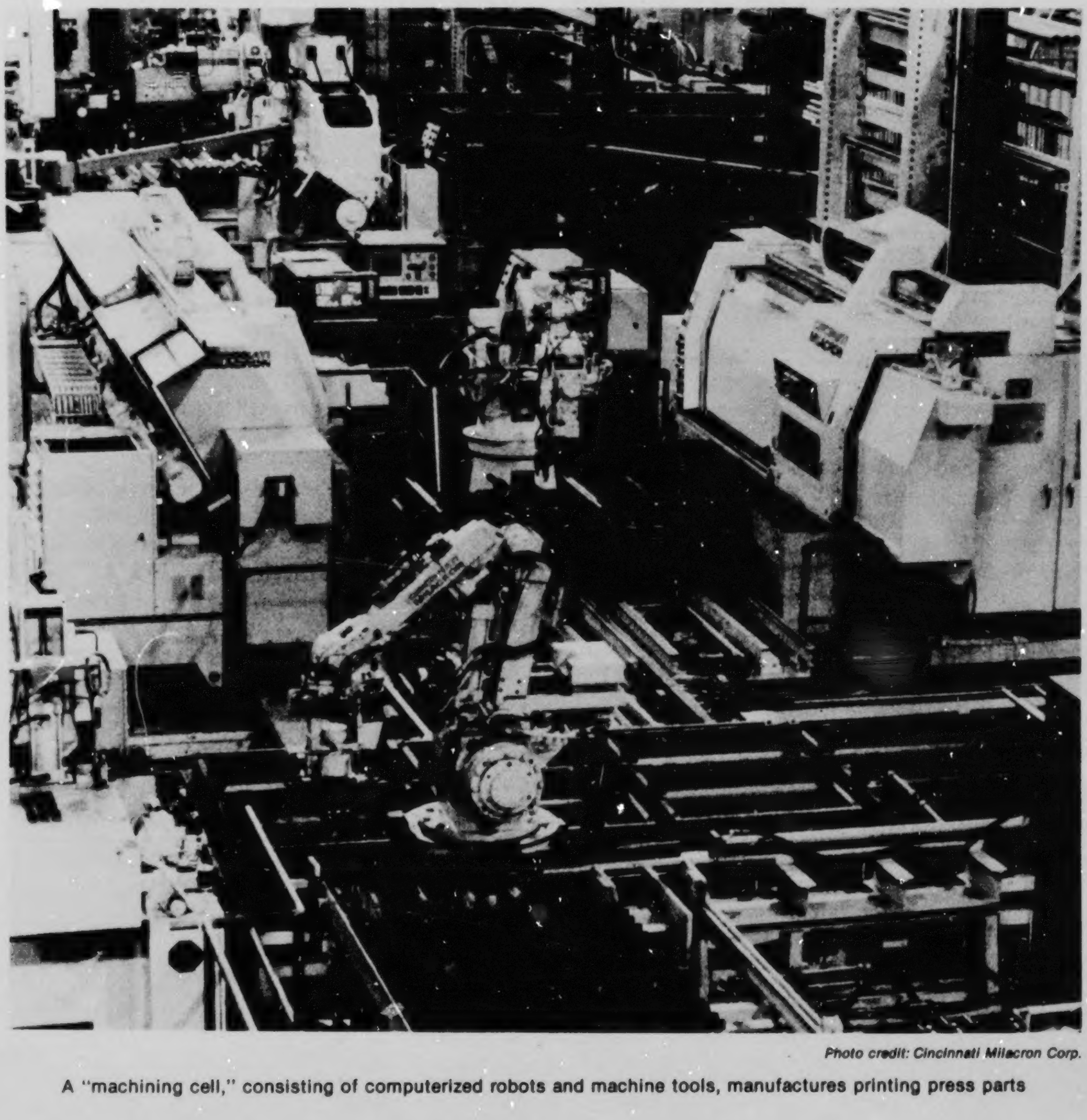

Photo credit: Cincinnati Milacron Corp.

A "machining cell," consisting of computerized robots and machine tools, manufactures printing press parts machine tools can cause boredom when there is no immediate need for operator intervention and application of problem-solving skills. In addition, skilled NC operators who did not write programs reported that operating an NC machine was significantly less challenging than operating a conventional machine.

Work-related stress is a significant feature of computer-automated workplaces. Stress is associated with working on very complicated, expensive, and highly integrated systems, and with lack of autonomy at work, extending in some cases to computerized monitoring by management. The combination of the complexity of the system and the pressure to minimize downtime because of the high cost of lost production adds up to substantial stress for some maintenance workers. Although each situation is different, excessive boredom and/or stress can often degrade the productivity of individual workers.

On the other hand, the introduction of programmable automation tends to have a favorable impact on the physical surroundings of work. For instance, robots are amenable to hazardous tasks in environments that are unpleasant and unhealthy for workers. However, certain precautions are necessary to avoid potential new safety hazards. In response to concerns about robot safety, groups in the United States, Western Europe, and Japan are providing guidelines for the safe use of robots.

Since the introduction of PA will increase the number of workers using video display terminals (VDTs) and reduce the number operating production machinery, the concerns that are currently being raised about potential VDT hazards apply to a whole new set of workers, including CAD operators. Although there is no evidence that VDTs emit unsafe levels of radiation or that VDT use is hazardous to vision, increased stress levels due to prolonged use of VDTs have been reported, and further study of the long-term effects of VDT use is necessary.

Overall, the potential physical hazards appear to be more amenable to solution than some of the psychological ones because they are more easily recognized and less subject to the subtleties of individual personalities. The relief of such symptoms as boredom and stress is more difficult, because they are not well understood and are often complicated by other factors not related to the workplace. **Depending on how tasks are arranged and jobs designed, programmable automation has the potential to decrease the amount of autonomy, control, and challenge available to the worker, or it can increase variety and decisionmaking opportunities.**

Management's strategies and motivations for introducing programmable automation are key in determining its impacts. In addition, the nature of labor-management relations will affect the implementation of new technology and its consequences for the work environment. In work environments that are becoming more and more automated, management is likely to seek increasing flexibility in deploying workers. This will be reflected in collective bargaining demands from management for changing work rules, in return for union demands for such employee benefits as job security. Formal labor-management cooperation in solving workplace problems has been growing in the United States. Where successful, these participative arrangements are likely to have a positive influence on the effects of new technology in the workplace, especially in the areas of job design, changing skills, and training.

In Europe and Japan, mechanisms for dealing with workplace concerns have generally been applied to the introduction of new technology. In many cases laws specify how such introduction is to be handled. For example, the laws of West Germany, Norway, and Sweden provide for worker involvement in technological change, and labor is routinely represented on corporate boards. It is important, however, to point out that the culture and traditions of Europe and Japan regarding attitudes and practices in the workplace differ from those of the United States, especially in the area of labor-management relations. These differences limit the transferability of foreign practices.

Education, Training, and Retraining Issues

Programmable automation is one of a number of forces that will reshape instructional services in the United States in the years ahead and create new demands for high-quality education, training, and retraining programs, as well as career guidance, job counseling, and placement services.

A prerequisite of PA-related instruction of all types is a strong foundation of basic skills—particularly reading, science, and math. The high level of functional illiteracy in the United States population is a major barrier to development of PA-related skills. Basic skills deficiencies have already surfaced as a problem in retraining some displaced manufacturing workers for jobs working with PA.

Analytical and problem-solving skills are increasing in importance for some skilled trades personnel and technicians, as well as other occupational groups common to automated facilities. Many who work with PA find themselves using conceptual skills more than motor skills. However, it is uncertain to what extent PA will require a substantial increase in the aggregate level of problem-solving and conceptual skill. As noted earlier, choices for implementing the technology can result in wide variations in worker input and control, and consequently a range of skill requirements.

Development of multiple skills and the "cross-training" of workers to perform a variety of functions on the shop floor are emerging instructional requirements for automated facilities, although not reflected as yet in many established instructional programs. Beyond acquiring a familiarity with PA, engineers in automated facilities need to develop an understanding of the entire design-to-manufacturing process and of how computerized equipment may be integrated with other machines and people for maximum efficiency and productivity. Continued industry pressure for more effective technical managers may well lead to greater emphasis on the development of management skills in industrial engineering and computer science education programs.

There is an immediate need for retraining and job counseling programs geared to the unique needs of displaced workers. In the past, many programs for displaced workers have failed to assess their existing competencies and provide opportunities to strengthen basic skills. As a result, participation rates have been low and dropout rates high in such retraining programs.

Ongoing changes in workplace skill requirements attributable to programmable automation and other factors point to the need for effective education and career guidance services for youth and adults. Individuals need access to current, reliable labor market information in order to make informed career choices and to pursue appropriate avenues of occupational preparation. The potential for frequent job change within the same economic sector or across sectors suggests that the numbers of adults seeking job counseling and placement assistance will increase dramatically in the years ahead. **At present, there are few programs that provide these kinds of education and career guidance services to youth and adults on an ongoing basis.**

While some institutions and organizations are providing PA instruction that addresses current skills requirements of computer-automated facilities, there are as yet no standard approaches to curriculum. **A common characteristic of successful programmable automation instructional programs examined by OTA was close cooperation and collaboration among educators, industry, labor, and government in assessing needs, developing curricula, and other activities.**

On the whole, the U.S. instructional system may not now be able to accommodate the potential demand for PA-related skills, which may in turn affect the rate of growth in PA applications. Shortages of technical instructors, state-of-the-art equipment and other resources are major problems for all segments of the instructional system, including industry-based education and training.

Programmable Automation Industries

While PA industries vary in size, there appear to be several hundred vendors in all. PA firms range from small companies supplying products to meet specialized market niches, to automation "supermarket" firms that offer multiple forms of PA. Many PA vendors are so-called turnkey firms, which package components made by different companies with software and other features into standard or customized systems. Small, innovative firms have played a key role as PA producers.

CAD, NC, robots, and other PA equipment and systems are sold by industries that are more or less separate. NC is the oldest and largest industry, dating from the 1950's. While CAD and robots were available by the 1960's, significant markets for them did not emerge until the 1970's. Markets for other PA products also began to flourish in the 1970's.

Although they grew slowly during the 1960's and early 1970's, **programmable automation markets grew rapidly in recent years and are expected to continue to do so.** Hence, it is hard to describe firms and industries in enduring terms. Moreover, as individual companies expand their product offerings and move to offer complementary products, a market for CIM may emerge. No one yet sells "CIM" as a total product, and some in industry contend that users are still pioneering the concept.

PA firms will affect the economy through their relationships with other industries as well as through their role as employers. Much of their economic impact will be realized indirectly, since their principal customers are other businesses that may use PA to improve their own performance. **Programmable automation industries are likely to become increasingly important to the industrial base and national security of the United States, because of increasing dependence on programmable automation both to enhance manufacturing productivity overall and to manufacture defense equipment.**

Competition among PA firms tends to center on software and customer services rather than on hardware features. This reflects growth in sales of PA systems (as opposed to single pieces of equipment). Indeed, PA vendors often rely on outside sources of hardware. They are offering a growing number of pre- and post-sale services, including applications engineering, training, maintenance, and software updates.

Programmable automation industries are characterized by high levels of interchange between firms. Licensing, outsourcing, mergers and acquisition, limited equity investments, and joint ventures are common, and often occur between firms from different countries. In this regard, PA industries are similar to the overall information-processing and electronics products industries. It is likely that vertical integration will continue to be limited and cooperative arrangements will continue to be made because new products are increasingly complex, product changes occur rapidly, and product development costs are growing. In the long term, however, international cross-fertilization may abate in favor of direct foreign investment.

In the near term, the growth of domestic producers of PA depends on whether domestic economic conditions are favorable to investment, and on the ability of U.S. managers to justify the necessary investments. Anticipated reductions in PA costs and growing understanding among managers of the potential benefits and costs of PA are likely to make companies increasingly receptive to PA. **In the long term, competition from foreign firms in domestic and foreign markets may constrain the growth and size of programmable automation industries.** Companies from many countries, often supported by foreign governments, have been involved in PA development and production since the 1960's, and many countries consider PA industries important features of their economies.

Research and Development

Both industry and government fund a broad range of research and development (R&D) in programmable automation. This work is undertaken in industry, university, and government laboratories.

Total Federal funding of automation R&D in fiscal year 1984 is budgeted at approximately $80 million, through four primary Government agencies—the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the National Bureau of Standards (NBS) (see table 3). R&D at both DOD and NASA is strongly mission-oriented (directed toward a particular agency goal), and it has limited applicability to commercial manufacturing. More generic or basic work is conducted through NSF and NBS.

DOD's Manufacturing Technology Program budgeted approximately $56 million in 1984 for work on automation technologies that could save money in defense manufacturing. Two other agencies within DOD, the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR), budgeted approximately $8 million for research in PA technologies for ultimate use in both defense manufacturing and battlefield applications. **Though DOD work in programmable automation is not intended to be widely applicable to commercial manufacturing, DOD sets themes for technology development in programmable automation. It serves as an informal coordination point for Government agencies and defense industries.**

Table 3.—Federal Funding of Research and Development in Programmable Automation, Fiscal Year 1984 (dollars in millions)

Military agencies:	
Manufacturing Technology (ManTech) Program	$56.00
Defense Advanced Research Projects Agency (DARPA)	3.50
Office of Naval Research (ONR)	4.10
Military subtotal	$63.60
Civilian agencies:	
National Bureau of Standards (NBS)	$3.85
National Aeronautics and Space Administration (NASA)	5.90
National Science Foundation (NSF)	6.90-9.20
Civilian subtotal	$16.65-18.95
Total Federal funding	$80.25-82.55

SOURCE: Office of Technology Assessment.

NASA's automation research concentrates on robotic tools for use in space. The research program is small and focused on technologies that are very sophisticated by commercial standards, though there are occasional spinoffs to commercial manufacturing.

NSF plays a small but important role in funding basic research in PA. The Production Research Program at NSF focuses on automation technologies, while at least a dozen other programs within NSF fund automation-related research to some degree. Total funding for 1984 is estimated to be about $7 million to $9 million.

NBS has a rather unique role in automation R&D in that it is the Government's primary inhouse laboratory for such work. NBS pursues automation R&D in standards (e.g., standardization of programing languages and standardization of interfaces between computerized tools), metrology (measurement of parts using computerized devices), and schemes for integrated manufacturing. **NBS' Automated Manufacturing Research Facility, funded largely through DOD, is perhaps the only full-scale testing facility for CIM in the United States.**

Estimates of CAD, robotics, and machine tool industry funding of automation R&D range from $264 million to $400 million in 1983, and they grow rapidly in the future as the industries expand. There is evidence of increased cooperation between industries and universities in the conduct of automation R&D. In particular, university-industry centers for R&D in programmable automation are proliferating.

The United States continues to be a world leader in many areas of R&D, including computer-aided design, software in general, and virtually all areas of basic research. Japan has developed substantial sophistication in many areas of robotics R&D, while Japan and West Germany are both strong in machine tool research. Both Japan and Western European countries also do significant research regarding manufacturing integration problems. Western European countries, notably Sweden and West Germany, conduct substantial research in work environment issues, while these issues receive only minimal attention in the United States.

International Policy Comparisons

All of the major industrialized nations support the development and use of PA to some extent. However, the lack of accurate, up-to-date information about the details of foreign government programs makes speculation about their effectiveness extremely risky.

Historical differences in national characteristics have strongly affected PA use internationally. For both Japan and Western European countries, these characteristics include a greater concern for cost reduction—presumably due to greater dependence on export markets, and to higher energy, materials, and capital costs than those in the United States prior to the 1970's. These factors have led to greater concern abroad for manufacturing processes with less materials waste, better product design, and low-cost production. The fact that the United States now faces similar constraints and a more competitive international environment is motivating U.S. manufacturers to focus more closely on manufacturing processes.

Government involvement in automation in **Japan** is substantial, but it is less monolithic than many believe. The influence of Japan's Ministry of International Trade and Industry (MITI) on Japanese industry is ebbing, although MITI continues to develop long-term plans for technological development and to target certain areas of technology for particular attention, such as robotics and microelectronics. Private industry expenditures comprise a greater percentage of total R&D spending in Japan than in any other country, in part due to the near absence of Japanese Government R&D in defense. The Government has, however, played a substantial role in encouraging application of new technologies in small and medium-sized firms and in facilitating cooperative efforts among PA producers and users.

Like the United States, the **West German** Government has no systematic industrial policy. It has played a large role in encouraging private industry investment, however, and has allocated large sums to semiautonomous research institutes and consortia which perform R&D related to manufacturing. In addition, the Government has established an Advanced Manufacturing Technologies Program to promote the riskier forms of innovation in this sector. Though the use of automation technologies in West Germany is not as extensive as in the United States or Japan, the West Germans have characteristically good government-labor-management relations which facilitate the introduction of new technology.

Sweden and **Norway** have recently begun to devote resources to PA in order to bolster economic growth. These countries are strong in robotics, work environment research, and education and training programs.

The **French** Government has a firm commitment to faster development and diffusion of PA, linking Government support to broad-based plans for restructuring French industries. Despite the availability of Government funds and loans, however, industry has not participated in Government programs to the extent anticipated.

Although the **British** Government is less involved in domestic industry than the Japanese or French, the United Kingdom has developed a set of "schemes" to promote investments in PA. These include loans and grants for consultants to help develop automation, and various mechanisms for support of industry and university R&D.

Italy has no overall industrial policy, although it promotes private investment in its underdeveloped southern regions. In addition, Italy is rapidly becoming a major producer of robots, and leading Italian firms have pioneered new applications.

Canada and **the Netherlands** have begun to promote PA to further economic growth. They have fledgling R&D programs and mechanisms for encouraging application of PA.

Implications for Federal Policy

The overarching policy question that emerges from this assessment is, "Should there be a national strategy for the development and use of programmable automation?" The opportunities and problems posed by PA are interconnected. Successful policy regarding PA must therefore mesh actions in several areas, something that can only be achieved through a multifaceted strategy. Further, the current uses and impacts of PA are a fraction of what they are expected to be in the long term. Thus, there is an opportunity for anticipatory Federal policy.

The principal issues which motivate interest in new policymaking include the relative immaturity of the technologies and lack of experience in their application; the fact that other countries are stimulating development and use of PA; the risk of unemployment growth as a result of PA use, both regionally and nationally; the risk of adverse effects on the psychological aspects of the work environment; and the ramifications of PA for education, training, and retraining.

A policy strategy for PA would have to balance the interests of a large and diverse group of stakeholders:

- The **developers and producers** of PA are primarily concerned with funding and facilities for R&D, as well as general economic policies which affect markets for the technologies.
- The **users** of PA focus on competition in their product markets. While they tend to resist government intervention in production and personnel areas, they call for improvements in tax and trade laws and other policies which influence the business climate.
- **Members of the labor force** care about whether they can get and keep jobs, what kind of jobs are open to them, and their relations with management. While approximately 20 percent of the labor force is represented by labor organizations, the bulk of the working population has no focused way to articulate its concerns.
- **Communities and State and local governments** are particularly concerned about economic development and maintaining their employment base.
- **Educators and trainers** are concerned about the funding, equipment, and facilities available to them, as well as making curricula responsive to new technologies and skill needs.
- Finally, the **Federal Government** has broad interests in the development and application of PA, including its use for building defense equipment, as well as its effect on productivity, economic growth, employment, and occupational safety and health.

Policy Strategies

If the Federal Government chooses to coordinate activities in areas of technology development and use, employment, work environment, and instruction, it can pursue one of four basic strategies:

1. **laissez-faire—a continuation of current policies;**
2. **technology-oriented—emphasis on programmable automation development and use;**
3. **human resource-oriented—upfront attention to education and training, work environment, and job creation; or**
4. **both technology- and human resource-oriented.**

The principal uncertainties clouding projections are the rate of advance of the technologies, and the relative success of efforts abroad to develop and apply PA and to increase sales penetration in domestic and foreign markets. The state of the economy is also a major and uncertain influence.

The principal arguments for a **laissez-faire** strategy are that additional Federal involvement may not be necessary for effective use of PA, and that it may be too early in the application of PA to assess appropriate Federal actions. The disadvantages of this strategy are the risk that other countries may adopt and benefit from PA faster than the United States, and the risk of losing an opportunity to adopt policies that could not only maximize the effective use of PA but also minimize negative social consequences.

A **technology-oriented strategy**—bolstering R&D as well as encouraging applications of the technologies—could help avert a decline in industrial output and employment caused by competitive losses to foreign industries. Other advantages of such a strategy are that it would help ensure U.S. technological superiority, and it could bolster national security by maintaining a sound industrial base. However, even if greater use of PA were a decisive competitive aid to U.S. firms, a strictly technology-oriented strategy could aggravate unemployment and work environment problems, as well as strain the capacities of education and training systems. The postponed costs of a technology-oriented strategy, particularly for assisting displaced workers, may offset some of the potential economic benefits of such a plan.

A **human resource-oriented strategy** would involve upfront investment in evaluating skill requirements, tailoring education, training, and retraining programs, and conducting research in relevant work environment and educational impacts of PA. Such a strategy could stabilize or diminish future adjustment assistance spending, and could prevent work environment problems. While human resource development can facilitate the use of PA and otherwise improve productivity, its effects on industrial output levels may be less evident than the effects of technology-oriented policy. The major disadvantage of a primarily human resource-oriented strategy is that it might not improve productivity or competitiveness enough to offset trends in other countries. As in the laissez-faire strategy, the United States would run the risk of a further erosion in industrial output levels and loss of technological superiority.

A **combined technology- and human resource-oriented strategy** could ensure technology development and increased competitiveness while minimizing social fallout. It would recognize the complementary contributions of equipment and of people in production, and help assure that human impacts are explicitly considered in PA development and use. The disadvantages of such a combined approach include the administrative and legal burdens of coordinating a wide range of Federal activities.

Specific Policy Options

Technology Development and Diffusion

Existing Federal policy toward manufacturing technology is piecemeal at best. In the area of R&D, four agencies with distinctly different mandates fund automation research, although only a small portion of this work has general applicability for commercial manufacturing. Only in the area of defense procurement is there a concerted Federal effort to coordinate product and process technology development and application.

Option: Fund Research and Development.—Congress could act to increase PA R&D by influencing both the overall level of funding and its distribution to various agencies and research topics. The current environment for PA R&D is relatively healthy. However, funding for more long-term, generic research in nonmilitary application areas is relatively thin. Since the bulk of federally sponsored R&D is centered on military applications, Congress may wish to raise funding specifically for generic research, primarily through the National Science Foundation and National Bureau of Standards. Congress may also wish to increase funding for standards and human factors research, which could facilitate the application of programmable automation across a wide range of industries.

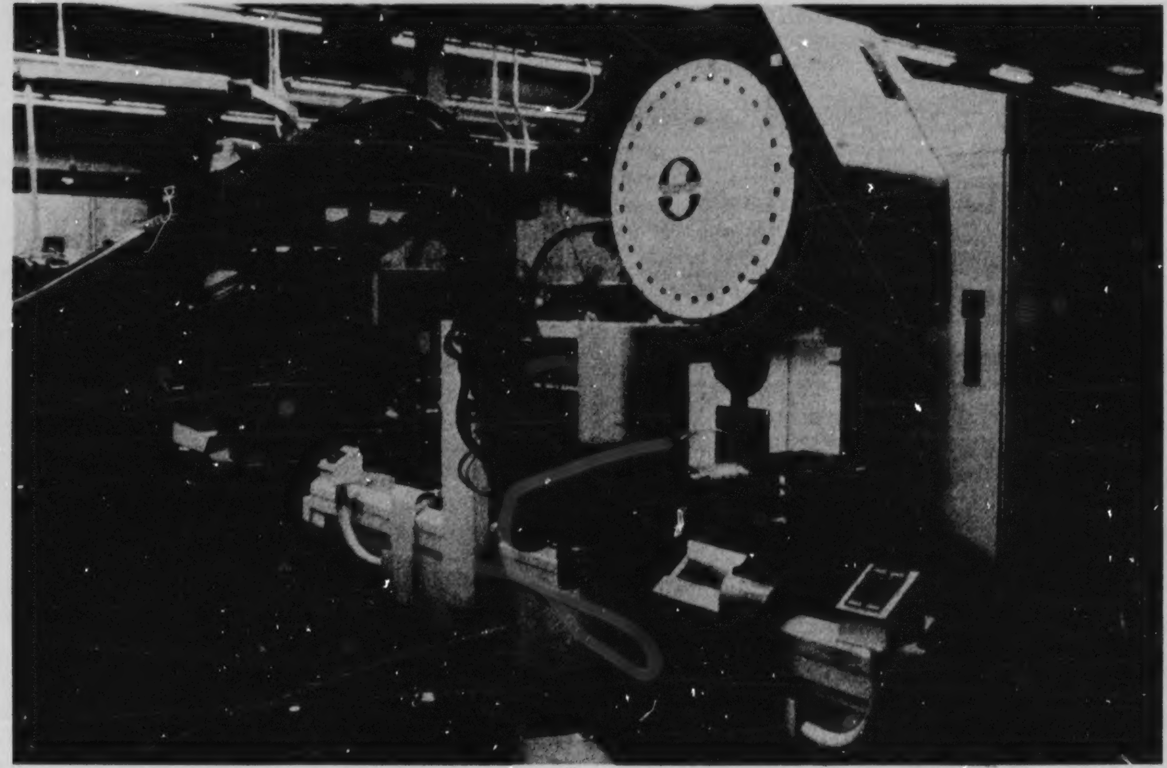

Photo credit: National Bureau of Standards

A robot loads a computerized machining center at the National Bureau of Standards' Automated Manufacturing Research Facility

Option: Facilitate Standard-setting.—In addition to bolstering R&D in standards, Congress may wish to consider legislation to facilitate standard-setting as a means of increasing the ease of use of the technologies and encouraging their application. The principal disadvantage of standard-setting is the risk that more rapid adoption of standards may provide short-term benefits for users but hinder future innovations which could be inconsistent with the standards.

Congress might consider legislation which would clarify the legal position of standard-setting groups. Currently, groups which oversee the intricate process of developing standards, such as professional and trade associations, can be held responsible for antitrust violations which specific standards may pose. In addition, Congress could consider mandating a more active role for the Federal Government in coordinating and promoting standard-setting efforts. A potential disadvantage of this option is that it would increase Federal involvement in PA markets.

Option: Encourage Use of the Technologies.—The appropriate rate for adoption of PA is a subject of contention. It depends on the rates of adoption among our trading partners, the extent of delay between invention and adoption of new technology, and the ability of the labor force and industries to adjust. There is probably a degree to which PA adoption can be facilitated by Federal efforts without incurring excess costs. Beyond some indefinite point, however, encouragement of the use of

PA may lead to ill-considered applications and excessive problems for employees and communities.

Federal options for facilitating application of PA primarily involve removing barriers. These options include assistance in providing capital for the purchase or lease of automation equipment, and providing information about PA to manufacturers.

Measures to encourage adoption of PA, however, are only a partial and short-term solution to manufacturing problems. **A longer-term solution involves redressing the historical U.S. inattention to manufacturing processes, organization, and management.** Though there is some evidence that the private sector has begun to address this need, Congress could play an important role in fostering the development of engineering curricula in universities which combine manufacturing, design, and human resource management activities; as well as encouraging research in manufacturing engineering topics. Further, Congress could establish some form of "manufacturing institute," perhaps building on the research centers already at NBS or at universities, to provide a focus for manufacturing technology, organization, and management issues. Such an institute could serve as an information clearinghouse for manufacturers, as well as a think tank with rotating fellowships for people from all parts of the manufacturing sector.

Employment

The United States has had major Federal programs for employment since the Depression era. Excluding education and training programs (see later in this chapter), existing Federal employment policy covers four broad categories: 1) the development and distribution of labor-market information, 2) income maintenance for the unemployed, 3) labor standards, and 4) job creation. Compared with policies in most European countries and Japan, U.S. labor market policy is reactive and uncoordinated, and it is not linked to other, industry-oriented programs for structural adjustment in the national economy.

Option: Maintain the Status Quo.—Existing Federal programs provide relatively limited Federal involvement in employment change. Though some might argue that this level of involvement is appropriate, the existing set of programs and institutions have several drawbacks. In the last two decades, Federal employment policy has come to focus on short-term programs for aiding disadvantaged groups of people (low-income or chronically unemployed or underemployed). In particular, current programs are ill-equipped to deal with long-term shifts in labor demand arising from technological and economic changes, growing uncertainty in skill requirements, and extended unemployment among groups other than the disadvantaged. Similarly, they are not designed to deal with large regional disparities in unemployment, a problem that PA will likely aggravate in the near term.

Option: Establish Programs for Job Creation.—Job creation programs can help decrease unemployment, as well as stimulate economic growth and help build the skills of the work force. The principal problem in developing a job creation program is to avoid paying for jobs that employers would have created anyway, and to avoid merely shifting employment from one industry to another, either of which would diminish net job growth.

Job creation programs range from the most general (i.e., expansionary macroeconomic policy) to specific measures to stimulate hiring, including tax credits, incentives for domestic production, change in average work hours, and increased production of public goods and services. In particular, the latter two types of job creation programs might be considered in the face of persistent labor surpluses. Although reducing average work hours can spread work among a larger group of people, individual employees may experience real wage losses. The actual costs and benefits of reducing work hours depend on how such a program is structured.

Similarly, stimulating production of so-called public goods and services would also create jobs. Production of public goods and services does not have to be met by expanded public sector employment. As in the case of defense procurement, public investment can stimulate private sector employment. "Public goods and services" can include a multitude of activities—from highway building to child care. The principal disadvantage of public goods programs historically has been the diversion of resources from private goods production.

Option: Expand Programs for Labor-Market Information.—PA offers the prospect of radical and ongoing changes in the deployment of labor among manufacturing firms. Monitoring of employment patterns by expanded collection and analysis of occupational employment data would provide a means of measuring the rate, extent, and direction of change. Expanded data collection by the Department of Labor and the Bureau of the Census would improve their ability to describe and forecast employment trends, and it would improve the information they disseminate to educators, counselors, and individuals. It would also provide data for comparing staffing patterns among firms—information that would be useful to managers, labor organizations, and educators. The primary argument against such efforts to expand labor-market information is rooted in the desire to reduce paperwork required of businesses, and to limit Government statistics to those that are specifically needed by Federal agencies.

Option: Expand Adjustment Assistance Programs.—Expanded programs for income maintenance or relocation assistance may be necessary to ease adjustment problems caused by PA and a variety of other factors. Although the debate over aid to displaced workers tends to focus on external aid, actions by employers themselves may also serve to ease employment shifts. Congress might consider legislation to encourage advance notice of technological change, which allows workers to plan for change, evaluate training needs, and seek new work. Employers often resist advance notice requirements, however, arguing that technological change is a management prerogative. Another measure that Congress might consider for employer actions would be financial incentives to relocate personnel either within or outside the firm.

Work Environment

OTA's analysis suggests that the area where PA itself may motivate the greatest departure from past Federal policy is work environment. Because PA will eventually affect the work environment of most manufacturing personnel, especially in metalworking manufacturing, and because it poses potential new problems pertaining to the psychological aspects of the work environment, this technology raises questions about the adequacy of existing mechanisms for studying, monitoring, and regulating workplace conditions.

Option: No Increased Federal Role.—Although no single policy instrument specifically addresses the impacts of PA on the work environment, various mechanisms are already in place at the Federal, State, and local levels that cover workplace concerns in general, particularly in the areas of health and safety. Further, a few efforts have begun in both the private and public sectors to plan for the workplace effects of the introduction to new technology. Finally, it may be too early in the development and application of PA to devise an appropriate Federal role. All the above concerns might argue for retaining the status quo.

However, work environment issues are similar in some ways to other problems, such as pollution, which are not easily solved by the private sector on its own. With current estimates of union membership in the United States totaling about one-fifth of all workers, there is a large segment of the population that will not have a focused way to articulate work environment concerns. Finally, there is a great deal to be learned about the effects of PA on the workplace, and such research must begin immediately in order to help improve the workplace as adoption of PA accelerates.

Option: Increase Oversight and Monitoring.—Congress could increase the emphasis placed on the workplace effects of computerized manufacturing automation through its oversight and monitoring activities. Considerable oversight has been provided on these issues by a number of congressional committees over the past several years. In addition to its own oversight activities, Congress could designate monitoring responsibilities to the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). While such oversight could inform Congress and the public about workplace concerns and cover a wide range of settings, it might result in a piecemeal effort with little or no coordination of activities or sharing of information.

Option: Increase Support for Work Environment Research.—Congress could support research, through such agencies as NIOSH, NSF, and the Department of Labor, on both the short- and long-term social impacts of PA on the workplace. Potential areas for research might include the physical and psychological effects of PA, management strategies and policies in introducing and using PA, worker participation, identification of hazards and how to control them, changes in work content and organization, and changes in organizational structure, among others. Research would be particularly valuable for identifying techniques to measure nonphysical problems in the workplace. Demonstration projects, seminars, and experiments would enhance understanding of the effects of PA and the extent to which it can be shaped to improve the work environment.

Current research on the social impacts of PA on the manufacturing work environment is modest in scope and support, reflecting the limited amount of interest and funding available for this purpose. By contrast, study of the impacts of new technology on the workplace is more common in Japan and Western Europe, where the subject has historically received more attention across sectors.

Option: Set New Standards.— New safety and health standards may be required to address problems associated with the use of PA. Reliable information would be needed on the numbers of people at risk, the nature of the risks, and the potential costs and benefits of establishing and enforcing new regulations.

Option: Promulgate Omnibus Work Environment Legislation.—Other aspects of the introduction of new technology into the workplace, beyond safety and health concerns, suggest that a broader approach to work environment policy may be desirable. These aspects include the potential for excessive surveillance of workers and the disparity in worker and management understanding of both the choices available in adopting PA and theie workplace ramifications. In addition, a broader approach would ensure that the interests of all workers would be protected.

A number of European countries have taken an omnibus approach to workplace concerns. In Norway and Sweden, for instance, work environment legislation has been in effect since 1977. One purpose of this legislation is to protect workers' mental as well as physical health in the workplace, particularly in the context of technology change; another is to give employees an opportunity to influence the design of the work environment.

Education, Training, and Retraining

The Federal role in education has traditionally been that of supplementing or enhancing State and local activities. In recent years there has been a movement toward lessening direct Federal involvement. In contrast, the Federal role in training and retraining efforts—particularly for the economically disadvantaged—has been dominant since the mid-1960's. In keeping with the trend toward decentralization, the recently enacted Job Training Partnership Act (JTPA) shifts responsibility for administration and regulation of federally funded training and retraining activities to the States.

Option: No Increased Federal Role.—As in other areas affected by PA, it may be too early to assess the appropriate Federal role in education, training, and retraining related to PA. However, if the Federal Government chose not to modify its existing programs, it would for-go potential roles unlikely to be assumed by other levels of government or the private sector, such as assisting in the coordination of instructional activities, ensuring that adequate labor market and occupational forecasts are developed, and ensuring that information derived from such forecasts is actively disseminated to individuals, educators, and trainers.

Option: Increase Support for Facilities, Equipment, and Qualified Instructors.—Congress could consider options such as tax incentives for the purchase of state-of-the-art equipment for training, and funding to establish selected educational facilities and maintain them for use in periods of intense demand for PA instruction. Congress is currently considering legislation to encourage interest in math and science teaching, engineering education, and other forms of technical instruction. While these measures could remove many of the barriers to the establishment of PA instructional programs, they might also stimulate too much interest in PA instruction at the expense of other types of education and training.

Option: Encourage Curriculum Development.—Congress could enact a grant program to fund the development of curricula geared to the development of PA-related skills. Encouraging comprehensive curriculum design and the establishment of voluntary guidelines for curriculum content at various levels would guarantee some degree of standardization to both enrollees and employers.

Option: Encourage Renewed Emphasis on Basic Skills and Problem-Solving Skills.—Congress could choose to encourage at all levels of instruction a renewed emphasis on strong, basic skills in reading, math, and science. Special emphasis could be placed on the development of individual problem-solving skills, since these are important prerequisites to training for careers in computerized manufacturing, as well as for nonmanufacturing occupations.

This option could make the labor supply more resilient in the long term by raising the overall skill level. It could also create a foundation of skills that could be enhanced over time through the development of job-related skills, including those associated with PA. Finally, this approach would not feed the process of "skills obsolescence" by tying individual instruction too closely to specific technologies.

Option: Encourage Individual Participation in PA-Related Instruction.—Possible measures already being considered by Congress to make individual participation in instruction more economical include individual tax incentives (e.g., deductions for spending on training for a new occupation); the designation of training as an allowable expense under the Unemployment Insurance System; and the establishment of individual education or training accounts. Incentives to individuals would be particularly valuable in instances where employers do not provide PA-related instruction to their employees beyond the level of introductory training.

Option: Encourage Industry-Based Instruction.—Few users of PA equipment currently have or plan to establish in-house instructional programs. Congress could choose to encourage users of programmable equipment to establish or enhance in-house technical training programs through the creation of tax incentives that help defray the costs of instructors, equipment, expansion of instructional facilities, and curriculum development.

Option: Intensify Research Efforts.—Congress could choose to increase Federal sponsorship of research to identify changing skills requirements within manufacturing occupations, and to provide for broad-based dissemination of the findings to better equip educators and trainers for curriculum development. Congress could also use a research program to encourage the development of instructional standards that are in keeping with PA skills requirements.

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Chapter 2

Introduction

Background

A new wave of automation is spreading through manufacturing industries, and like its predecessors, it is receiving a mixed welcome. Computerized manufacturing automation—the application of electronic computer and communication tools to manufacturing—is viewed both as contributing to the problems faced by the U.S. economy and as part of the solution to those problems.* Those who view it optimistically emphasize its potential to improve productivity, work environment, product quality, and ultimately competitiveness. Those taking the opposite view argue that it will cause massive unemployment, make many jobs less rewarding, and provoke a retraining crisis. The rhetoric used by both sides makes it difficult to appraise the technologies and, more importantly, to determine what policies may be appropriate.

The economic and social effects of computers and automation in manufacturing have aroused concern since the late 1950's. During the late 1950's and early 1960's, people grew more aware of the potential uses of computer technology, while adoption of so-called hard or dedicated automation began to accelerate. Studies conducted during that period, including the report of a Federal study commission, drew conclusions about potential job loss, changing work conditions, and instructional needs that remain valid today.[1] Because of technological developments and falling costs for computing during the late 1960's and the 1970's, the prospects for significant social and economic change resulting from wide use of computer technologies are more immediate today than before.

The current wave of automation is unlike its predecessors in several ways: Programmable automation (PA) can collect and process information as well as do physical work, allowing equipment for design, production, and management to be linked together. It can improve product quality by raising consistency and control in production. And it can be used in producing a range of products because of its reprogrammability. This trait, in particular, lies behind claims for PA "flexibility". These features make PA economical in production of much smaller quantities than hard automation, which is largely restricted to large quantity or mass production. They make PA applicable across a wide range of industries, whereas the applicability of conventional hard automation is much more limited. PA will have a major influence on skill requirements, product design and variety, production costs, job content, and the organization and management of manufacturing. Its features are fundamental to the potential changes in employment, work environment, and education and training needs that are a focus of this report.

The technical features of programmable automation and their economic and social ramifications will continue to make PA a source of controversy over the next decade. In particular, the economic aspects are central to the argument proponents make for rapid development and diffusion of programmable automation. Proponents claim that, in the current climate of international competition, manufacturing firms must either automate or move production overseas if they are to continue in business.* The basic argument states that PA will make domestic manufacturing more efficient and competitive, and it will thereby contribute to economic growth and greater employment.

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*The subject of this report is described as "manufacturing" rather than "factory" automation in order to emphasize that these tools can be applied not only to the fabrication of products but also to the critical functions of product design and manufacturing management. Related office automation technologies is being evaluated in a forthcoming OTA study, "Information and Communication Technologies and the Office."

[1] Report of the National Commission on Technology, Automation, and Economic Progress, 1966.

*Barring, that is, significant changes in import restraints or the value of the dollar.

The focus on economic growth reflects concern over the slow growth in productivity and economic output experienced during the 1970's and early 1980's. During that time, U.S. industries lost shares in domestic and foreign markets to foreign competitors, principally the Japanese. While the causes and significance of these phenomena are debated even among experts, popular consensus deems a key cause to be different production costs—in particular, different labor costs—among countries and industries. Lower costs abroad for labor have been a major reason, but not the only one,* for increases in overseas production by U.S. manufacturers as well as for increased imports of manufacturing goods. Against this background, the labor-savings aspects of PA technologies have taken on special significance.

Unfortunately, the popular focus on the labor-savings aspects of programmable automation is misleading: It plays on historic tensions between labor and management in this country, and it ignores the role of management, product design, and other cost factors in determining a company's ability to compete. There is a risk that, by emphasizing the one-for-one substitution of machines for people, companies will use PA inefficiently; they may ignore critical differences between what people and machines can do best, and they may ignore less tangible but effective options for improving human resource management or responsiveness to customer needs.**

PA will help many companies to produce better and cheaper. But whether the policy goal is to improve industrial competitiveness, maximize employment, or both, OTA's research reveals a need for comprehensive rethinking of manufacturing processes and competitive strategies. With surprising consistency, automation experts consulted by OTA cited organizational factors, rather than technical ones, as the principal problems surrounding the use of PA. Thus, in several cases, PA feasibility studies have led to improvements in product design and production processes without the adoption of PA equipment. While new technology—i.e., new ways to combine equipment, personnel, and materials—can help manufacturing companies, experiences in the United States and abroad reveal that the success or failure of PA depends more on the management characteristics of the organizations that use it than on the particular choice of equipment and systems.

The technological, social, and economic concerns surrounding the spread of programmable automation are interconnected. Labor-saving technology does not necessarily cause unemployment: employment depends on what and how much consumers will buy, as well as how management decides to make those goods. Technology does not of itself raise or lower the skill levels required of employees: skill requirements depend on how management defines jobs and allocates work to suit an existing or preferred work force. Machines do not necessarily improve or degrade the work environment: equipment designers and managers make choices that determine how machines and people interact.

Programmable automation can improve the work environment, raise productivity, and create or preserve at least some jobs if it is developed and applied with those goals in mind. Because the markets for PA are still young and the use of PA is still relatively limited, the near-term social and economic effects of PA will not be cataclysmic. There is time for managers, employees, educators, and government to gain a better understanding of PA and to plan to address the effects of automation on the workplace. Such advance planning will be necessary in order for the country to capture the potential benefits of PA and avoid excessive social and economic costs. Specific areas where long-range planning would be beneficial include analysis of changing skill requirements, improvements on the pairings of people with machines, and the roles and requirements for various educational institutions. Also important is the business climate for PA vendors and users.

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*Other reasons include such factors as differences in materials and energy costs, differences in capital markets, the exchange rate, and changes in market size.

**This capital-spending bias was brought out by a recent survey of industrial engineers. (Institute of Industrial Engineers, "Productivity Today: An Inside Report," 1983.) As one reporter noted, "It seems clear that while more companies could benefit from trying to better use their employees, the role of capital spending—traditionally the 'quick fix' for improved industrial performance—will remain a major component of corporate strategy." Philip Moeller, "Firms Try To Boost Output," *The (Baltimore) Sun*, Oct. 19, 1983.

Study Approach, Organization, and Methodology

Approach

To appreciate what programmable automation bodes for the U.S. economy, it is necessary to understand its key features, including its limitations and side effects as well as its expected benefits. This report examines those features largely from the perspective of the individual firm that may adopt PA. It focuses on the use of PA among discrete-product manufacturers,* particularly those in such metalworking industries as transportation equipment and electrical and nonelectrical machinery. These industries have been and will through this century continue to be leading users of PA. While many of the conclusions reached about the application of PA in metalworking industries may hold for other industries, generalizing about long-term effects of PA across industries—even among metalworking industries—is risky.

Where uncertainties exist, they are identified. Often, those uncertainties surround estimates of the amounts of change that are likely to arise from the spread of PA. The reliability of inferences about quantitative effects on industries, regions, and the national economy is limited because good data on economic and social aspects of PA do not exist. In particular, there is a scarcity of good data describing shifts in skill requirements, types of jobs, materials requirements, or the structure and competitive conduct of industries producing and using programmable automation. Consequently, it is too early to make precise, quantitative forecasts. Moreover, because technology, industry, and job characteristics are changing continually, descriptions of conditions at any one point will not necessarily hold up over time. **This report therefore stresses the identification of the nature and direction of likely changes rather than their magnitudes.**

This report examines a wide range of potential changes in the development and use of human resources that may accompany the spread of PA. Some will shape industry employment prospects, others will affect the work environment. Indeed, potential changes in the work environment will ultimately affect more people than changes in industry employment levels. While developments in employment and in the work environment may motivate new education and training activities, education and training in turn may shape the development, use, and employment effects of PA. In describing the ramifications of programmable automation for human resources, this report addresses the potential for nontechnological factors, from management style to industrial structure, to reinforce or conflict with the influences of PA itself.

The international context for PA development and use is highlighted throughout the report. While data on activities and programs abroad are limited and uneven in quality, each chapter relates phenomena in the United States to those abroad to the extent feasible. Actions in many countries will affect the level of technological development, the strength of the United States' claim to technological leadership, and the ability of producers and users of PA to compete in domestic and foreign markets.

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*Producers of discrete products made in lots ranging from one to mass-production quantity, such as industrial machines and automobiles, as opposed to continuous-process manufacturers, such as producers of chemicals and steel.

Organization and Methodology

Following the executive summary and introduction, the prospects for programmable automation are examined in this report from several perspectives. Those perspectives are brought out through seven analytical and descriptive chapters. A final chapter presents congressional policy options. Each chapter draws on other chapters in the report, but is otherwise self-contained.

Chapter 3 addresses the questions, "What is programmable automation?" and "How might it be used?" It defines **PA technologies**—including computer-aided design, robots and other forms of computer-aided manufacturing, and related computer-based management systems—and describes their development trends. This chapter stresses the fact that PA is much bigger than robotics, which receives most of the attention, and it evaluates the potential for the integration of PA equipment into highly automated systems.

Chapters 4, 5, and 6 address the question, "What are the implications of its use?" Chapter 4 examines the prospects for **employment change**, including the ways in which PA may influence job design and the number and mix of jobs among firms and industries. It also highlights conflicting influences on employment by occupation and industry. Chapter 5 explores the implications of the use of PA for the workplace. The chapter shows how technological features combine with management attitudes and actions to shape the **work environment** in manufacturing firms. Chapter 6 illuminates emerging needs for **education, training, and retraining** and discusses current efforts by industry, labor, and the academic community to meet those needs. It also discusses the relationship between PA-related skills development and broader educational preparation.

Chapter 7 addresses the questions, "Who produces PA equipment?" and "What is the status of producer industries?" It describes the structure and competitive conduct of **industries** supplying programmable automation goods and services. The chapter also characterizes the emerging role of these industries in the U.S. and world economies.

Chapters 8 and 9 provide background on the players involved and on existing directions in U.S. and foreign technology policy. Chapter 8 describes the roles of public and private institutions conducting PA **research and development**. Chapter 9 enumerates the efforts of **governments in other countries** to stimulate the production and use of programmable automation. These two chapters lead into chapter 10, which provides alternatives for congressional action.

The findings and insights of this report were developed from many sources of information. Technical literature and conference sessions provided background materials, but more direct development of information constituted the bulk of the research. Over the course of the study, OTA held workshops that brought together experts in the areas of employment change and industrial relations, programmable automation industries, and programmable automation technologies. OTA also conducted a survey of education, training, and retraining activities and opinions among producers and users of PA and among educators. In addition, 18 case studies were carried out. Fourteen described approaches to education, training, or retraining; four described some of the effects of PA on the work environment. Throughout the study, OTA staff visited facilities and consulted with a wide range of experts.

Congressional Interest and Policy

The computerized manufacturing automation study was requested by the Joint Economic Committee, the Senate Committee on Labor and Human Resources, the Senate Committee on Commerce, Science, and Transportation, and the Labor Standards Subcommittee of the House Committee on Education and Labor. Other committees, including the House Committee on Science and Technology and the House Committee on Small Business, have also expressed interest in this study. Table 4 lists several relevant congressional hearings held during the development and conduct of this assessment.

Table 4.—Representative Recent Congressional Hearings Relevant to Programmable Automation

Robotics
June 2 and 23, 1982, 97th Cong., 2d sess.
Hearings before the Subcommittee on Investigations and Oversight to examine the status and potential applications of robotics technology R&D.

New Technology in the American Workplace
June 23, 1982, 97th Cong., 2d sess.
Hearing before the Subcommittee on Labor Standards to examine the impact of automation on employment and working conditions.

Hearings on Mathematics and Science Education
Sept. 28-30, 1982, 97th Cong., 2d sess.; and Jan. 26-28 and 31, 1983, 98th Cong., 1st sess.
Hearings before the Subcommittee on Elementary, Secondary, and Vocational Education and the Subcommittee on Postsecondary Education to consider several bills to improve mathematics and science education at the elementary and secondary level.

Oversight of Trade Adjustment Assistance Programs and Authorization of Appropriations for U.S. Trade Representative, International Trade Commission, and Customs Service
Mar. 17, 1983, 98th Cong., 1st sess.
Hearings before the Subcommittee on International Trade to consider the impacts of foreign trade and the fiscal year 1984 activities of concerned Federal agencies.

Impact of Robotics on Employment
Mar. 18, 1983, 98th Cong., 1st sess.
Hearing before the Subcommittee on Economic Goals and Intergovernmental Policy to examine the impact of automation, including robotics, on U.S. employment.

Biological Clocks and Shift Work Scheduling
Mar. 23 and 24, 1983, 98th Cong., 1st sess.
Hearings before the Subcommittee on Investigations and Oversight to examine research on human biological rhythms, such as the sleep-wake cycle, and their effect on job performance of shift workers.

Job Forecasting
Apr. 6 and 7, 1983, 98th Cong., 1st sess.
Hearings before the Subcommittee on Investigations and Oversight to examine implications of technology change for employment forecasting.

The Impact of Robots and Computers on the Workforce in the 1980's
May 17, 1983, 98th Cong., 1st sess.
Hearing before the Subcommittee on General Oversight and the Economy on employment forecasting and technological change.

Administration Proposal for Block Grant for Vocational and Adult Education
May 19, 1983, 98th Cong., 1st sess.
Hearings before the Subcommittee on Elementary, Secondary, and Vocational Education regarding the formulation and administration of Federal education grants to States.

Technology and Employment
June 7-10, 14-16, and 23, 1983, 98th Cong. 1st sess.
Joint hearings before the Subcommittee on Science, Research, and Technology and the Task Force on Education and Employment regarding the range of effects of new technology on labor.

Industrial Policy, Economic Growth and the Competitiveness of U.S. Industry
June 24, 29, and 30; and July 13, 14, and 20, 1983, 98th Cong., 1st sess.
Hearings to examine issues and recommendations relating to a national industrial policy to facilitate industry capital formation in order to promote and sustain economic growth.

Joint Hearing on Plant Closing
July 8, 1983, 98th Cong., 1st sess.
Joint hearing before the Subcommittee on Employment Opportunities and the Subcommittee on Labor-Management Relations of the Committee on Education and Labor regarding a bill to set conditions on plant closings.

Industrial Policy: the Retraining Needs of the Nation's Long-term, Structurally Unemployed Workers
Sept. 16, 23, 26, and Oct. 26, 1983, 98th Cong., 1st sess.
Hearings before the Joint Economic Committee on national retraining needs associated with structural change in the economy.

SOURCE: Office of Technology Assessment.

The extensive congressional interest in the study reflects the fact that programmable automation has numerous implications for policy. Recent policy discussions have tended to focus on either labor issues or international competitiveness. Indeed, concern for labor issues was a strong theme in the requests for the study.

This report addresses policy concerns in the areas of work environment, employment, education and training, and the development and use of programmable automation. Moreover, the policy discussion in chapter 10 emphasizes the interconnections between impacts and policies in all of those areas. It provides alternatives for congressional action that address those areas together as well as individually.

Chapter 3

Programmable Automation Technologies

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Chapter 3

Programmable Automation Technologies

Summary

This chapter is both a primer on programmable automation (PA) tools and their potential applications in manufacturing, and an assessment of the important problems and directions for development of the technologies. As defined here, programmable automation includes computer-aided design (CAD); computer-aided manufacturing tools—e.g., robotics, numerically controlled (NC) machine tools, flexible manufacturing systems (FMS), and automated materials handling (AMH); and computer-aided techniques for management—e.g., management information systems (MIS) and computer-aided planning (CAP). When systems for design, manufacturing, and management are used together in a coordinated system, the result is computer-integrated manufacturing (CIM).

The context for this analysis is primarily discrete manufacturing, as opposed to continuous-process industries such as chemicals or paper. Discrete manufacturing includes a wide range of traditional metalworking industries (e.g., automobiles and farm equipment) as well as other industries which are not primarily metalworking (e.g., electronics). Of particular note is that a great many of the products of discrete manufacturing are made in batches of perhaps a few dozen to a few hundred units. Because of this, it is often not economical to use single-purpose, automated machines (known as "fixed" or "hard" automation) to manufacture the product. In such an environment, programmable automation is potentially very useful.

The essential difference between conventional factory machines and programmable automation is the latter's use of information technology to provide machine control and communication. The use of computers and communications systems allows these machines to perform a greater variety of tasks than fixed automation can perform, and to automate some tasks which previously necessitated direct human control.

Programmable automation can respond to some of the central problems of manufacturing. These include enhancing information flow, improving coordination, and increasing efficiency and flexibility (defined as both the range of products and volume of a specific product which a factory can economically produce). By using programmable automation to address these problems, manufacturers hope to increase their productivity and control over the manufacturing process.

Though labor savings seem to be the most obvious benefit of automation, savings through more efficient use of materials may be more significant in many manufacturing environments. In particular, flexible manufacturing systems can reduce waste, reduce levels of finished product inventory, and reduce the manufacturer's substantial investment in the products that are in various stages of completion, known as "work in process."

Some of the technical factors which hold back PA's potential uses in manufacturing include relatively cumbersome programing languages, a general level of technical immaturity in many areas of the technologies, long-established organizational barriers in industry (e.g., between manufacturing and design engineers), and the embryonic nature of efforts to maximize the effectiveness of man-machine interactions.

Nevertheless, the technologies appear to be quite adequate technically for the vast majority of near-term applications; there seems to be a significant backlog of available tools which manufacturers have only begun to exploit.

The use of PA tools in integrated systems—e.g., FMS or CIM—is much more powerful than their use for a single task or process. Such integration not only magnifies the productivity and efficiency benefits of PA, but also tends to induce changes in all parts of the factory. Management strategies, product designs, and materials flow all change to best make use of such integrated systems.

Many industrialists have a vision of CIM that includes maximum use of PA tools and coordination between them, with few if any human workers. Others downplay CIM as a revolutionary change and emphasize that factories will adopt automation technologies as appropriate. It may not be appropriate (or economical) to remove all or most humans from many factories. In any case, the widespread use of CIM and virtually unmanned factories are unlikely to arise before the turn of the century.

Principal themes in the future development of PA technologies include increasing their versatility and power, enhancing their capability to operate without human intervention, and developing the ability of the tools to be integrated. Researchers and industry spokesmen report progress in virtually all the fundamental technical areas, although many of the currently identified problems in programmable automation are complex enough to keep researchers busy for many years to come. According to many experts, the 1990's may bring many major technical advances which could significantly expand the range of problems to which programmable automation can be applied.

Introduction

The purpose of this chapter is to describe the technologies that together comprise "programmable automation," and to evaluate their usefulness for manufacturing. In addition, the chapter examines how the technologies are evolving and what can be expected for the capabilities and applications of these tools.

Programmable automation refers to a family of technologies that lie at the intersection of computer science and manufacturing engineering. "Programmable" means that they can be switched from one task to another with relative ease by changing the (usually) computerized instructions; "automation" implies that they perform a significant part of their functions without direct human intervention. The common element in these tools that makes them different from traditional manufacturing tools is their use of the computer to manipulate and store data, and the use of related microelectronics technology to allow communication of data to other machines in the factory.*

There are three general categories of functions which these tools perform—they are used to help **design** products, to help **manufacture** (both fabricate and assemble) products on the factory floor, and to assist in **management** of many factory operations. Table 5 outlines the principal technologies included in these categories, each of which will be described in the next section.

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*Although "programmable automation" is less common than some of the other terms used to describe automation technologies, it is a relatively simple and unambiguous term for the tools discussed here. "CAD/CAM" (computer-aided design/computer-aided manufacturing) is a catch-all term used in industry journals and popular articles to refer to a set of technologies similar to the set defined here as programmable automation. However, CAD/CAM is also used to describe some specific computer-aided design systems, or to denote the integration of computer-aided design and manufacturing. Because of this ambiguity, the term will not be used here. "Robotics" is another term that is sometimes used in a broad sense to mean not only robots but the whole family of automation tools.

Table 5.—Principal Programmable Automation Technologies

- I. **Computer-aided design (CAD)**
  - A. Computer-aided drafting
  - B. Computer-aided engineering (CAE)
- II. Computer-aided manufacturing (CAM)
  - **A. Robots**
  - **B. Numerically controlled (NC) machine tools**
  - **C. Flexible manufacturing systems (FMS)**
  - D. Automated materials handling (AMH) and automated storage and retrieval systems (AS/RS)
- III. Tools and strategies for manufacturing management
  - **A. Computer-integrated manufacturing (CIM)**
  - B. Management information systems (MIS)
  - C. Computer-aided planning (CAP) and computer-aided process planning (CAPP)

NOTE: Bold type indicates technologies on which this report concentrates.
SOURCE: Office of Technology Assessment.

The three categories of automation technologies—tools for design, manufacturing, and management—are not mutually exclusive. In fact, the goal of much current research in automation systems is to break down the barriers between them so that design and manufacturing systems are inextricably linked. However, these three categories are useful to frame the discussion, particularly since they correspond to the organization of a typical manufacturing firm.

Further, this report does not attempt to cover each of the technologies in equal detail. It concentrates on those five which appear in bold type in table 5 because they are the core technologies of PA and their potential uses are most extensive.

Discrete Manufacturing

Some background about manufacturing is important to provide a context for assessing the usefulness of these tools. Programmable automation can affect many kinds of industry. This report focuses on PA applications for discrete manufacturing—the design, manufacture and assembly of products ranging from bolts to aircraft. The report does not systematically cover nonmanufacturing applications such as architecture, or continuous-process manufacturing—e.g., chemicals, paper, and steel. Other recent OTA reports have examined technological changes affecting process industries.[1]

Electronics manufacturing industries do not fit neatly into a discrete v. process classification. Some areas, particularly the fabrication of semiconductors, most resemble continuous-process manufacturing. Other portions such as circuit board assembly are more discrete. Because electronics industries have been leaders among metalworking firms in both producing and using computerized factory automation, they play a key role in this report.

To many industrialists, discrete manufacturing means metalworking for mechanical applications—shaping, forming, and finishing metals into usable products such as engine blocks. However, an increasing proportion of mechanical parts manufacturing involves plastics, fiber composites, or new, durable ceramics. These new materials both enable new production processes and are themselves affected by automation technologies.

One way in which discrete manufacturing plants can be categorized that is especially relevant to automation applications is the volume of a given part that they produce. As figure 1 indicates, discrete manufacturing represents a continuum from piece or custom production of a single part to mass production of many thousands. Although many people are most familiar with mass-production factories, with their assembly and transfer lines, it is estimated that mass production accounts for only 20 percent of metalworking parts pro-

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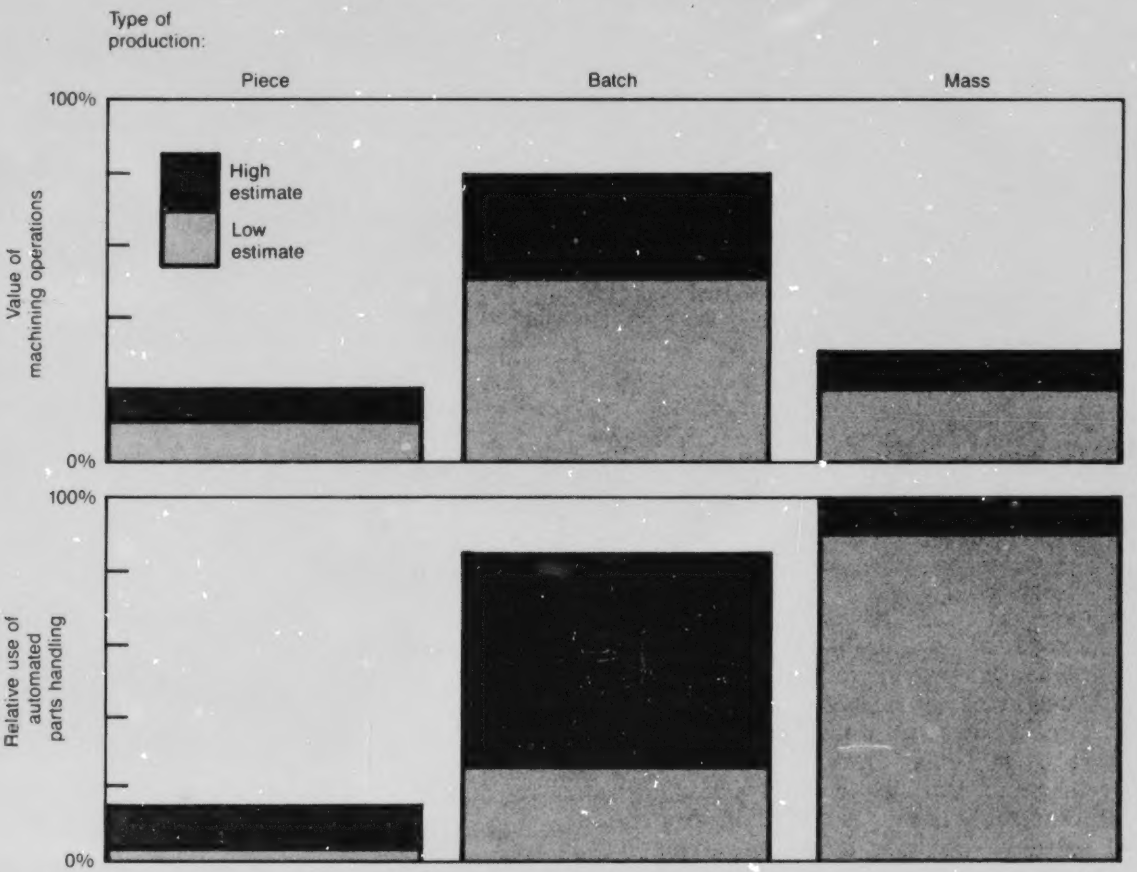
[1] Cf. *U.S. Industrial Competitiveness: A Comparison of Steel, Electronics, and Automobiles* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-ISC-135, July 1982); *Technology and Steel Industry Competitiveness* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-M-122, June 1980).

Figure 1.—Characteristics of Metalworking Production, By Lot Size



Typical lot size: Large complex part	1-10	10-300	Over 200
Typical lot size: Small simple part	1-300	300-15,000	Over 10,000
Typical products	Aircraft, large turbines, centrifuges	Marine engines, large electric motors, tractors	Autos, fasteners, small appliances
Typical machines	**Manual machine tools, or stand-alone numerically controlled (NC) machine tools**	**NC machine tools with automated part-handling machining cell flexible manufacturing system**	**Transfer lines, dedicated or special machines**

SOURCE: Machine Tool Task Force, *Technology of Machine Tools*, October 1980.

duced in the United States, while 75 percent are made in a "batch" environment.[2] The definition of a "batch" varies according to the complexity of the part and the characteristics of the industry. A common characteristic of batch manufacturing is that there is not enough volume to justify specialized machines (known as "hard automation") to automatically produce the part. The direct labor involved in fabricating products in batches is relatively high (as shown in fig. 1), and constitutes a large proportion of the cost of the item. These characteristics of batch manufacturing—its prevalence, and its low level of automation and correspondingly high level of labor content—are important because they suggest a broad range of uses for programmable automation.

The Manufacturing Process

Figure 2 illustrates the organization of a hypothetical metalworking manufacturing plant. Most of the elements in this diagram are present in some form in each plant, although factories are tremendously varied in size, nature and variety of products, and production technologies. One automobile factory in New Jersey, for example, assembles 1,000 cars per day in two models (sedan and wagon) with 4,000 employees; a small Connecticut machine shop, by contrast, employs 10 people to make hundreds of different metal parts for aircraft and medical equipment, typically in batches of approximately 250.[3]

As illustrated in figure 3, the manufacturing process usually begins when management decides to make a new product based on information from its marketing staff, or (in the case of the many factories which produce parts of other companies' products) management receives a contract to produce a certain part. Management sends the specifications for the size, shape, function, and desired performance of the product to its design engineering staff, who are responsible for developing the plans for the product.* In most companies, design engineers make a rough drawing of the product, and then draftsmen and design detailers are responsible for working out the detailed shapes and specifications.

In some discrete manufacturing firms, design may be undertaken at a distant location, or at a different firm. Automobiles, for example, are designed at central facilities, and the component subassemblies—e.g., bodies, transmissions, engines—are produced in plants all over the world.

The design of a product, especially a product of some complexity, involves an intricate set of tradeoffs between marketing considerations, materials and manufacturing costs, and the capabilities and strengths of the company. The number of choices involved in design is immense. Determining which of many alternative designs is "best" involves making choices among perhaps 100,000 different materials, each with different characteristics of strength, cost, and appearance; it also involves choices between different shapes and arrangements of parts which will differ in ease of fabrication and assembly (sometimes called "manufacturability") and in performance.

From the design, the production engineering staff determines the "process plan"—machines, staff, and materials which will be used to make the product. Production planning, like design, involves a set of complex choices. In a mass production plant that manufactures only a few products, such as the auto plant described above, production engineering is a relatively well-structured problem. With high volumes and fairly reliable expectations about the products to be made, decisions about appropriate levels of automation, for example,

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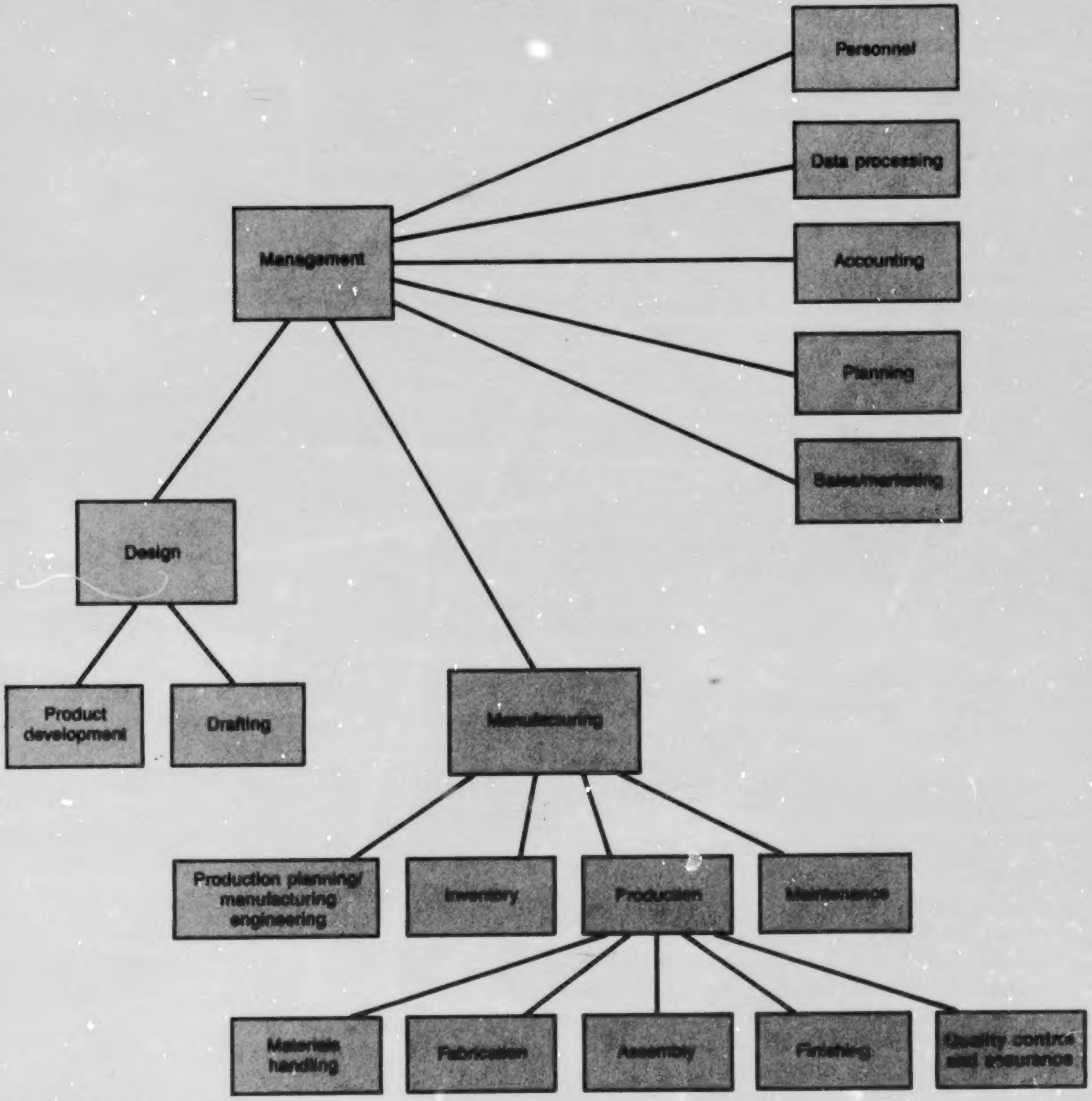
[2] M. E. Merchant, "The Inexorable Push for Automated Production," *Production Engineering*, January 1977, pp. 44-49. This 75 percent figure has become something of a legend in the metalworking industry largely through Merchant's writings, though he notes that he has lost track of the original reference for the statistic. While it is hard to substantiate given the diversity of metalworking industry, Merchant and other industry experts cite it as a good rough estimate. Personal communication, M. E. Merchant, Nov. 7, 1983.

[3] OTA work environment case studies.

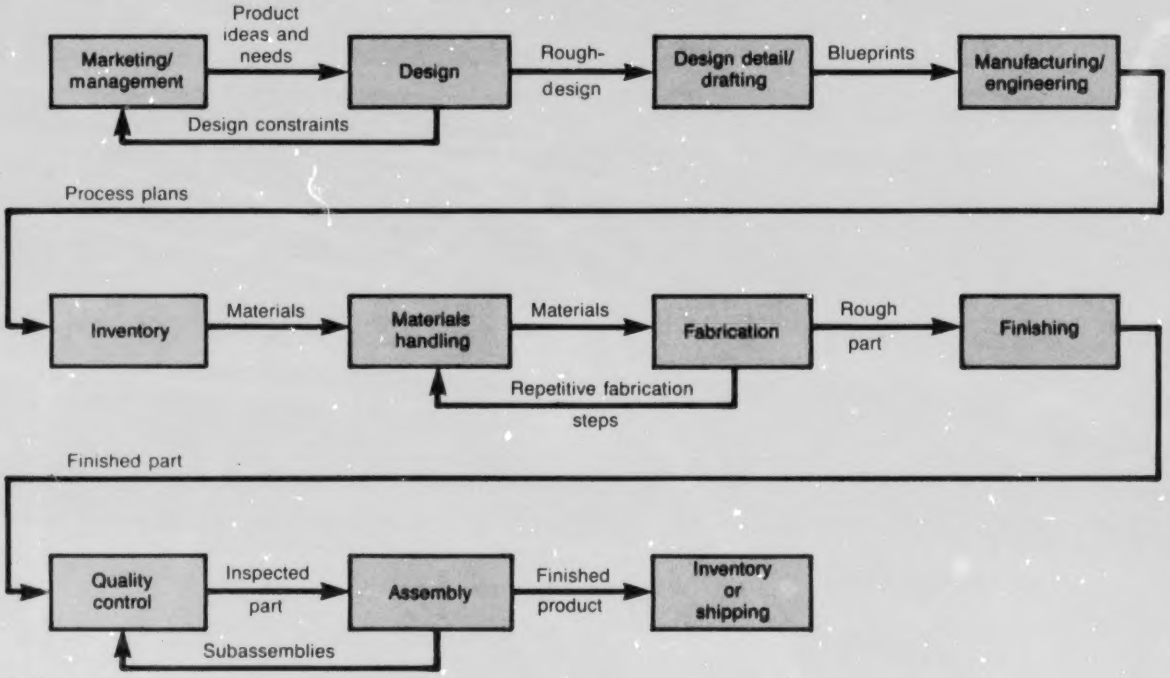
*In this description, as in the rest of the chapter, titles such as "manager," "design engineer," or "draftsman" indicate the person who performs these functions. In an actual company the roles may be less distinct, and boundaries between them frequently changing.

Figure 2.—Organizational Diagram of a Manufacturing Firm


Personnel
Data processing
Management
Accounting
Planning
Sales/marketing
Design
Product development
Drafting
Manufacturing
Production planning/ manufacturing engineering
Inventory
Production
Maintenance
Materials handling
Fabrication
Assembly
Finishing
Quality control and assurance

SOURCE: Office of Technology Assessment.

Figure 3.—Steps in the Manufacturing Process (Simplified)


Marketing/ management
Product ideas and needs
Design
Design constraints
Rough-design
Design detail/ drafting
Blueprints
Manufacturing/ engineering
Process plans
Inventory
Materials
Materials handling
Materials
Fabrication
Repetitive fabrication steps
Rough part
Finishing
Finished part
Quality control
Inspected part
Assembly
Subassemblies
Finished product
Inventory or shipping

SOURCE: Office of Technology Assessment

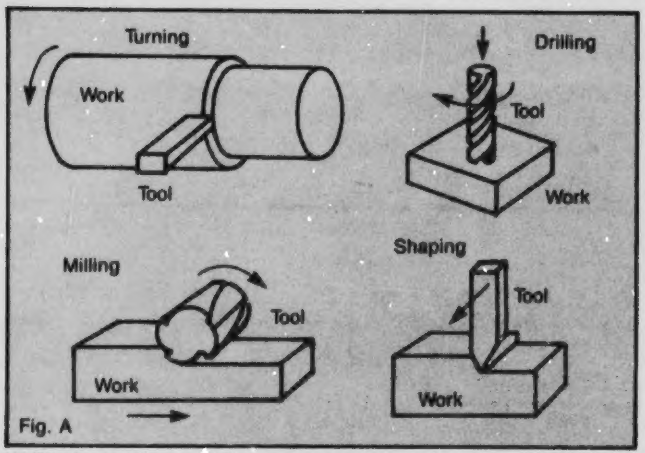
are relatively straightforward. On the other hand, for a small "batch" manufacturer such as the Connecticut machine shop referred to above, production engineering decisions can be rather chaotic. Such an environment involves almost continuous change in the number and types of parts being produced (size, shape, finish, material), the tools and levels of skill needed to produce them, and unpredictables such as machine breakdowns and inventory control problems.

The steps in production are immensely varied, but most products typically require the following:

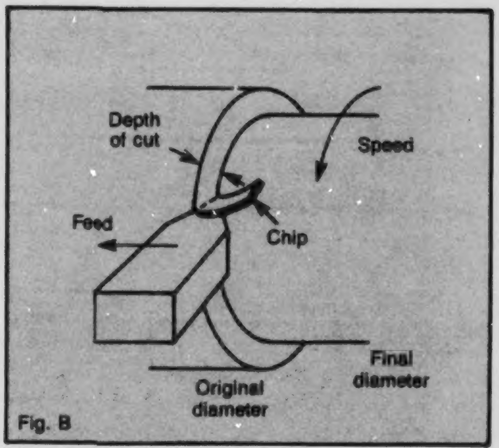
1. *Materials handling.*—Materials are brought from inventory to processing stations, and from one station to another. Wheeled carts, forklift trucks, or conveyors are typically used for this purpose. Early in the production process, large parts are mounted on a pallet or fixture to hold them in place and facilitate materials handling.
2. *Fabrication.*—There is a tremendous variety of fabrication processes. Plastic and ceramic parts are extruded or molded; layers of composite fiber material are treated and "laid up." The most common sequence for three-dimensional (3-D) metal parts is casting or forging, followed by machining.

Figure 4 illustrates the basic machining processes which are the core of metalworking. The shape and size of the metal part, as well as the desired finish and precision, determines the machine to be used. Some machine tools, such as lathes, are designed for cylindrical parts, e.g., drive shafts or rotors. Others, such as planers, are designed for prismatic parts with basically flat outer surfaces, e.g., engine blocks. Abrasive cutting of metal produces "chips," the metal shavings re-

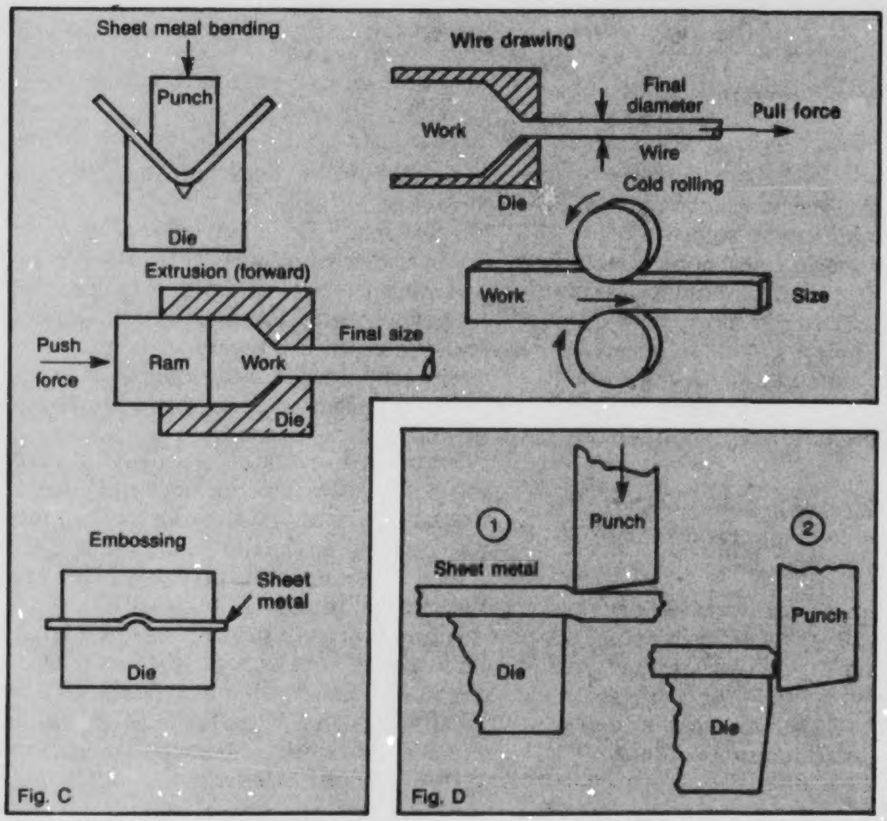
Figure 4.—Fundamental Operations in Metalworking


Turning
Work
Tool
Drilling
Tool
Work
Milling
Tool
Work
Shaping
Tool
Work
Fig. A

[A] The four basic machining processes can, between them, theoretically produce any contour on a workpiece. Although the processes are old, they are the foundation of metalworking and are being made more productive and accurate.


Depth of cut
Speed
Feed
Chip
Final diameter
Original diameter
Fig. B

[B] In any of the basic machining processes, speed, feed, and depth of cut determine productivity. The three variables are shown here for turning on a lathe.


Sheet metal bending
Punch
Die
Wire drawing
Final diameter
Pull force
Work
Wire
Die
Cold rolling
Work
Size
Extrusion (forward)
Push force
Ram
Work
Final size
Die
Embossing
Sheet metal
Die
Fig. C
1
2
Punch
Sheet metal
Die
Punch
Die
Fig. D

[C] Forming operations bend, squeeze, or stretch metal, imparting new sizes or shapes, or both.

[D] Shearing deforms metal beyond its breaking point, thereby separating one portion of a metal sheet from another.

SOURCE: M. P. Groover, "Fundamental Operations," *IEEE Spectrum*, vol. 20, No. 5, May 1983. Reprinted with permission of *IEEE Spectrum*. ©IEEE.

moved from the part, and these chips must be frequently removed from the machine and recycled or disposed.

Simple parts may be machined in a few minutes; large, complex ones such as ship propellers may take up to a few days. The complexity of these parts is primarily a function of their geometry—a propeller, for example, has continuously varying and precise curves. Similarly, the complexity of a prismatic part depends on the number of edges and required tolerances —i.e., the amount a part or surface can vary from its specified dimensions. Complex parts usually require machining on more than one machine tool. Including all machining operations, the total time from metal "blank" to finished part may vary from a few minutes to a few weeks. The partially completed "workpieces" awaiting further machining, finishing, assembly, or testing are known as work-in-process inventories, and often represent a substantial investment for the manufacturer.

Finally, there are several kinds of metal parts which are not machined. These include sheet metal parts, which are stamped and/or bent in sheet-metal presses, and parts made by "powder metallurgy," a technology for forming metal parts in near-final shape by applying extreme pressure and heat to metal powder.

3. *Finishing.*—Many fabrication processes leave "burrs" on the part which must be removed by subsequent operations. In some cases, parts are also washed, painted, polished, or coated.
4. *Assembly.*—The finished parts are put together to produce a final product or, alternatively, to produce "subassemblies" which are portions of the final product. In most factories assembly is still primarily a manual activity, although this phase of manufacturing is receiving increased attention, ranging from design strategies that minimize and simplify assembly tasks to automation of the tasks themselves.
5. *Quality assurance and control.*—There are many quality strategies. They can be divided roughly into those that take place before or during fabrication and assembly (quality assurance or QA) and those that take place after a product or subassembly is complete (quality control or QC). Quality has been receiving increasing attention in industrial literature and discussions, although the extent to which companies are actually paying more attention to quality on the factory floor is uncertain. There appears to be a movement toward QA as opposed to QC in order to enhance quality and prevent the production of faulty products, as opposed to detecting flaws after production. Strategies for QA range from "quality circles," in which a team of employees helps address production issues which affect quality, to in-process measurement of products as they are manufactured. In the latter, developing problems in production equipment can sometimes be detected and corrected before the machine makes a bad part. Most complex products are produced with some combination of QA and QC.

   Strategies for attaining the more traditional quality control vary widely according to the nature and complexity of the part. The dimensions of mechanical products can be measured, either with manual instruments or with a Coordinate Measuring Machine or laser measurement device; or the product can be compared to one of known quality or to a master gage. Electronic products can be tested with other electronic devices or probes.

This brief outline of the manufacturing process suggests some of the key problems in manufacturing. Underlying each of these problems are the central concerns for any business, those of minimizing cost and risk. The problems include:

- *Information flow.*—In any company, small or large, the amount of information that must flow between and among design, manufacturing, and management staff is staggering. For example, in a design process involving several teams of people, how does one make sure that all design and manufacturing personnel are working from the most up-to-date set of plans? How can staff get up-to-date information on the status of a particular batch of parts, or the performance of a particular machine tool or manufacturing department? How can the company keep track of work-in-process and other inventory?

- *Coordination.*—Beyond merely obtaining information in a timely fashion, the company must use that information to determine how to effectively coordinate its operations. One set of such issues involves coordination of design and production efforts. How can one design products which can be manufactured most efficiently with a given set of tools? How can one minimize the number of parts in order to facilitate assembly? Another set of coordination issues arises on the factory floor itself. What is the most efficient way to allocate machines and personnel? How does one adapt the schedule when conditions inevitably change (raw materials don't arrive, production is slower than expected, etc.)?
- *Efficiency.*—Given a large set of choices regarding tools, personnel, and factory organization, a company generally seeks to make the most products using the fewest resources. This involves concerns such as: How can the company minimize expensive work-in-process inventories? How can manufacturers maximize the percentage of time spent making parts, as opposed to moving them, repairing or setting up machines, and planning? How can the use of expensive capital equipment be maximized? Finally, quality issues within the production process can have a large impact on efficiency. How can manufacturers maximize the number of products made right the first time, and hence minimize scrap, rework to correct manufacturing errors, and testing?
- *Flexibility.*—Increasingly, issues of flexibility and responsiveness in the manufacturing enterprise are prominent for manufacturers, especially for traditional "mass production" plants. Flexibility is defined here as the range of products and the range of volumes of a specific product which a plant can economically produce. Increased levels of competition, shorter product cycles, and increased demands for customized products are some of the reasons for an emphasis on flexibility. This concern raises such questions as: How can the turnaround time for design and manufacture of a product be reduced? How can the "setup" time for producing a new product be reduced? What is the optimum level of technology for both economy of production and maximum flexibility?

Programmable automation offers improvements in each of these four key areas of manufacturing by applying computerized techniques to control tools of production, to gather and manipulate information about the manufacturing process, and to design and plan that process. Further, the use of PA promises for many manufacturers an increase in their degree of control over the enterprise. Many industrialists argue that the more closely manufacturing processes are tied to one another, and the more information is readily available about those processes, the less chance there is for human error or discretion to introduce unknown elements into the operation. Such control is much harder to realize than it appears in theory. The issue of control will be a recurrent theme in this and subsequent chapters of this report.

In summary, programmable automation can help make factories "leaner" and more responsive, hence reducing both costs and risks in manufacturing. It is not, however, a panacea for problems in manufacturing. Each factory has different appropriate levels of automation, and there are technical and organizational barriers to implementing programmable automation most effectively. PA's capabilities and characteristics from a technical standpoint will be elaborated in the rest of this chapter, beginning with functional descriptions of the technologies themselves. The organizational and social concerns will be addressed at length in following chapters of the report.

Functional Descriptions

This section briefly describes the operation of each programmable automation technology and its applications in manufacturing.

Computer-Aided Design (CAD)

In its simpler forms, CAD is an electronic drawing board for design engineers and draftsmen. Instead of drawing a detailed design with pencil and paper, these individuals work at a computer terminal, instructing the computer to combine various lines and curves to produce a drawing of a part and its specifications. In its more complex forms, CAD can be used to communicate to manufacturing equipment the specifications and process for making a product. Finally, CAD is also the core of computer-aided engineering, in which engineers can analyze a design and maximize a product's performance using the computerized representation of the product.

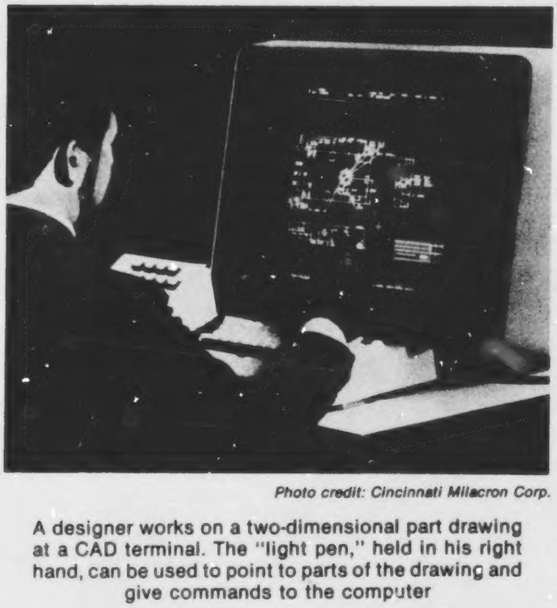


Photo credit: Cincinnati Milacron Corp.

A designer works on a two-dimensional part drawing at a CAD terminal. The "light pen," held in his right hand, can be used to point to parts of the drawing and give commands to the computer

The roots of computer-aided design technology are primarily in computer science. CAD evolved from research carried out in the late 1950's and early 1960's on interactive computer graphics—simply, the use of computer screens to display and manipulate lines and shapes instead of numbers and text. As S. H. Chasen of Lockheed-Georgia describes the rationale behind this research: "The ability of the computer to spill out reams of geometric data had outpaced our ability to cope with it."[4] SKETCHPAD, funded by the Department of Defense (DOD) and demonstrated at Massachusetts Institute of Technology in 1963, was a milestone in CAD development. Users could draw pictures on a screen and manipulate them with a "light pen"—a pen-shaped object wired to the computer which locates points on the screen. Such early systems were expensive prototypes and required most of the computing power of the then-largest computers. As a consequence, most of the early users of CAD were aerospace, automobile, and electronics manufacturers.

Several key developments in the 1960's and 1970's facilitated the maturation of CAD technology. They included the continuing decrease in cost of computing power, especially with the development of powerful mini- and microcomputers, which were primarily a result of electronics manufacturers learning to squeeze more and more circuitry into an integrated circuit chip. Another important technological advance was the development of cheaper, more efficient display screens. In addition, computer scientists began to develop very powerful programing techniques for manipulating computerized images.

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[4] S. H. Chasen, "Historical Highlights of Interactive Computer Graphics," *Mechanical Engineering*, November 1981, pp. 22-41.

How CAD Works.—There are various schemes for input of a design to the computer system, each with its advantages and disadvantages. Every CAD system is equipped with a keyboard, although other devices are often more useful for entering and manipulating shapes. The operator can point to areas of the screen with a light pen or use a graphics tablet, which is an electronically touch-sensitive drawing board; a device called a "mouse" can be traced on an adjacent surface to move a pointer around on the screen. If there is already a rough design or model for the product, the operator can use a "digitizer" to read the contours of the model into computer memory, and then manipulate a drawing of the model on the screen. Finally, if the part is similar to one that has already been designed using the CAD system, the operator can recall the old design from computer memory and edit the drawing on the screen.

CAD systems typically have a library of stored shapes and commands to facilitate the input of designs. There are four basic functions performed by a CAD system which can enhance the productivity of a designer or draftsman. First, CAD allows "replication," the ability to take part of the image and use it in several other areas of the design when a product has repetitive features. Second, the systems can "translate" parts of the image from one location on the screen to another. Third is "scaling," in which CAD can "zoom in" on a small part, or change the size or proportions of one part of the image in relation to the others. Finally, "rotation" allows the operator to see the design from different angles or perspectives. Using such commands, operators can perform sophisticated manipulations of the drawing, some of which are difficult or impossible to achieve with pencil and paper. Repetitive designs, or designs in which one part of the image is a small modification of a previous drawing, can be done much more quickly through CAD. On the other hand, CAD can be cumbersome, especially for inexperienced users. Drawing an unusual shape may be fairly straightforward with a pencil, but quite complex to accomplish using the basic lines and curves in the system's library.

The simplest CAD systems are two-dimensional (2-D), like pencil-and-paper drawings. And like sets of those drawings, they can be used to model 3-D objects if several 2-D drawings from various perspectives are combined. For some applications, such as electronic circuit design, 2-D drawings are sufficient. More sophisticated CAD systems have been developed in the past few years which allow the operator to construct a 3-D image on the screen,* a capability which is particularly useful for complex mechanical products.

Most CAD systems include a few CAD terminals connected to a central mainframe or minicomputer, although some recently developed systems use stand-alone microcomputers. As the operator produces a drawing, it is stored in computer memory, typically on a magnetic disk. The collection of digitized drawings in computer storage becomes a design data base, and this data base is then readily accessible to other designers, managers, or manufacturing staff.

CAD operators have several options for output of their design. All systems have a plotter, which is capable of producing precise and often multicolor paper copies of the drawing. Some systems can generate copies of the design on microfilm or microfiche for compact storage. Others are capable of generating photographic output. In most cases, however, the paper output from CAD is much less important than it is in a manual design process. More important is the fact that the design is stored on a computer disk; it is this version which is most up-to-date and accessible, and

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*In a practical sense, any image on a computer screen is two-dimensional. The difference between a "3-D" image as discussed here and any other 2-D drawing that appears three-dimensional (e.g., a painting, a photograph or any drawing with perspective) is that this image, unlike a paper drawing, can be manipulated as if it were a real 3-D object. For example, the operator can instruct the CAD system to rotate the object, and he/she then sees another face of the object.

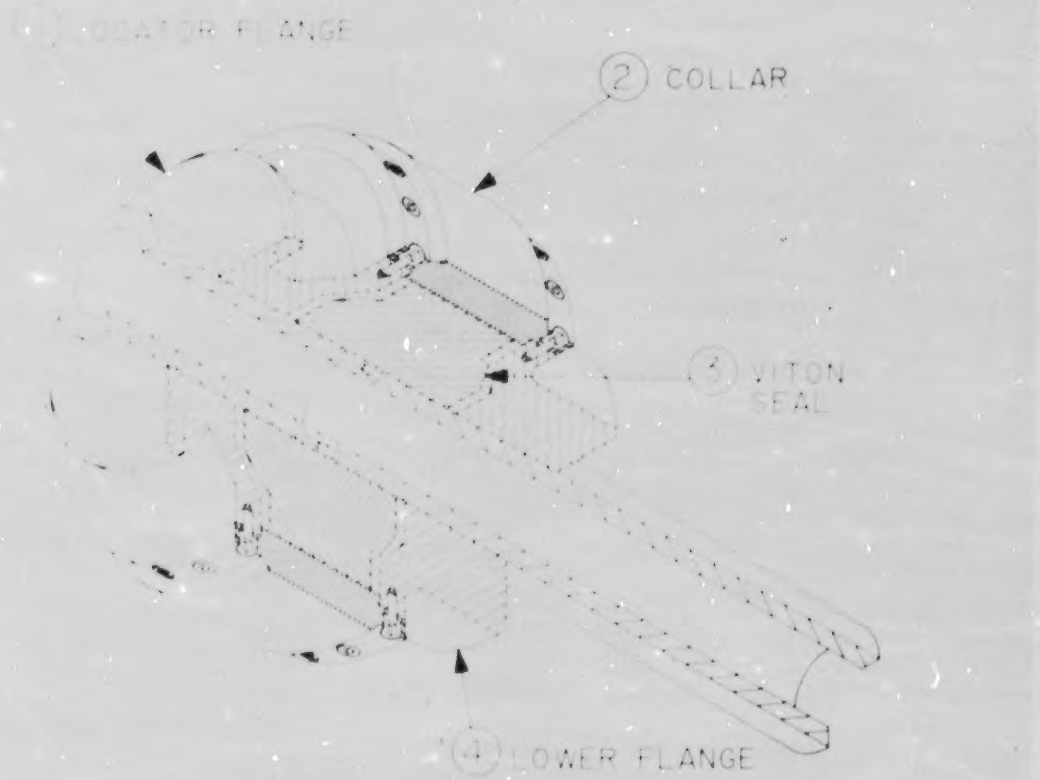

Illustration credit: Computervision Corp.

The designer has removed a section of this three-dimensional CAD image in order to better visualize part relationships and assembly information

which will be modified as design changes occur.

The CAD systems described above are essentially draftsmen's versions of word processors, allowing operators to create and easily modify an electronic version of a drawing. However, more sophisticated CAD systems can go beyond computer-aided drafting in two important ways.

First, such systems increasingly allow the physical dimensions of the product, and the steps necessary to produce it, to be developed via the computer and communicated electronically to computer-aided manufacturing equipment. Some of these systems present a graphic simulation of the machining process on the screen, and guide the operator step-by-step in planning the machining process. The CAD system can then produce a tape which is fed into the machine tool controller and used to guide the machine tool path. Such connections from computer-aided design equipment to computer-aided manufacturing equipment shortcut several steps in the conventional manufacturing process. They cut down the time necessary for a manufacturing engineer to interpret design drawings and establish machining plans; they facilitate process planning by providing a visualization of the machining process; and they reduce the time necessary for machinists to interpret process plans and guide the machine tool through the process.

Second, these more sophisticated CAD systems serve as the core technology for many forms of computer-aided engineering (CAE). Beyond using computer graphics merely to facilitate drafting and design changes, CAE tools permit interactive design and analysis. Engineers can, for example, use computer graphic techniques for simulation and animation of products, to visualize the operation of a product or to obtain an estimate of its performance. Other CAE programs can help engineers perform finite element analysis—essentially, breaking down complex mechanical objects into a network of hundreds of simpler elements to determine stresses and deformations. Computerization in general made finite element analysis feasible for the engineer's use, while CAD systems make it significantly less cumbersome by assisting the engineer in breaking down the object into "elements."

Many of these analytical functions are dependent on 3-D CAD systems which can not only draw the design but also perform "solid modeling"—i.e., the machine can calculate and display such solid characteristics as the volume and density of the object. Solid-modeling capabilities are among the most complex features of CAD technology, and will be discussed in more detail in later sections of this chapter.

Applications.—At the end of 1983 there were an estimated 32,000 CAD workstations in the United States.[5]

Aerospace and electronics uses of CAD have always led the state of the art. For example, the Boeing Commercial Airplane Co., which began using CAD in the late 1950's, employed the technology extensively in the design of its new-generation 757 and 767 aircraft. Boeing uses CAD to design families of similar parts such as wing ribs and floor beams. CAD allows designers to make full use of similarities between parts so that redesign and redrafting are minimized. Moreover, CAD has greatly simplified the task of designing airplane interiors and cargo compartments, which are often different for each plane. Moving seats, galleys, and lavatories is relatively simple with CAD, and the system is then used to generate instructions for the machines which later drill and assemble floor panels according to the layout. Finally, Boeing uses CAD and related interactive computer graphics systems as the basis for computer-aided engineering applications such as checking mechanism clearances and simulating flight performance of various parts and systems.[6]

Computer-aided engineering has also become important in the automobile and aerospace industries, where weight can be a critical factor in the design of products. These industries have developed CAE programs which can optimize a design for minimum material used while maintaining strength.

Applications for the design of integrated circuits are similarly advanced. Very large-scale integrated (VLSI) circuits, for example, have become so complicated that it is virtually im-

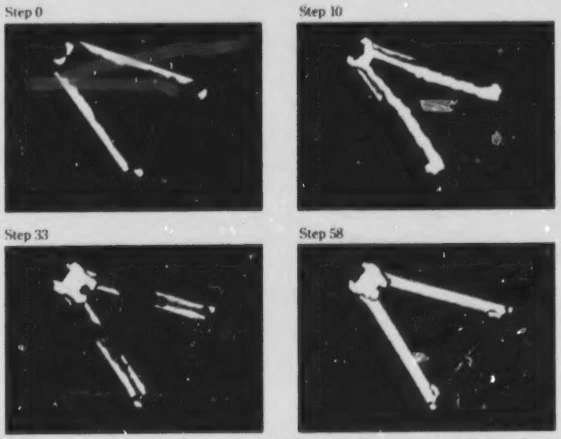

Illustration credit: General Motors Corp.

A computer-aided engineering system developed at General Motors Research Laboratories can help designers develop parts which are of minimum mass, yet are capable of performing under the structural loads. The CAE system tries to make the part thinner and lighter with each step; shading changes which appear on the computer screen show simulated stress levels within the design limits for this part possible for a person to manually keep track of the circuit paths and make sure the patterns are correct. There is less need here for geometrically sophisticated CAD systems (integrated circuit designs are essentially a few layers of two-dimensional lines), and more need for computer-aided engineering systems to help the designer cope with the intricate arrangement of the circuit pattern. Such CAE programs are used to simulate the performance of a circuit and check it for "faults," as well as to optimize the use of space on the chip.[7]

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[5] Source: Dataquest.

[6] W. D. Beeby, (former) Director of Engineering Computing Systems, Boeing Commercial Airplane Co., "Applications of Computer-Aided Design on the 767" (Seattle: Boeing, 1983).

CAD is also beginning to be used for nonaerospace mechanical design, and in smaller firms; these developments are being spurred on by the marketing of relatively low-priced "turnkey" systems—complete packages of software and hardware which, theoretically, are ready to use as soon as they are delivered and installed. While a standard and reasonably powerful system based on a minicomputer is typically in the $500,000 range, many smaller microcomputer-based systems have been introduced in the past year for under $100,000, in some cases for as low as $10,000 to $20,000. Very low-cost systems which run on common microcomputers have been introduced, and these have potential uses in a wide variety of firms which otherwise might not consider CAD (see ch. 7). The cost of custom-developed, specialized systems such as those described above for aerospace and electronics applications is harder to gauge but runs well into the millions of dollars.

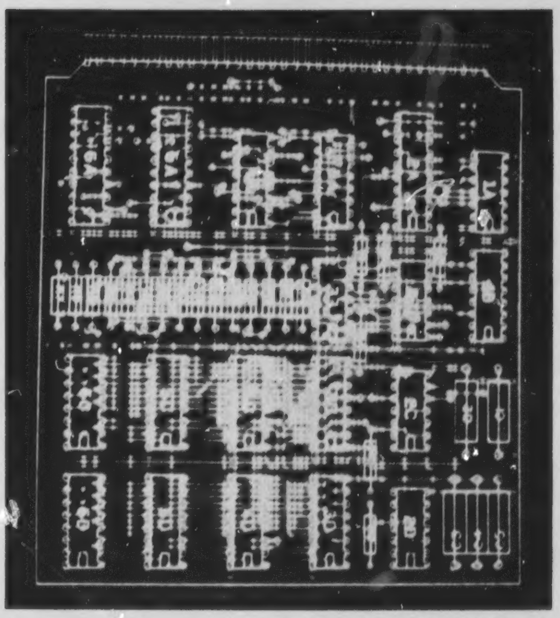

Photo credit: Computervision Corp.

CAD systems are used frequently in electronics industries to design and analyze complex circuit patterns

The potential advantage of CAD for large as well as small mechanical manufacturing firms is that it addresses several of the problems in manufacturing referred to at the beginning of this chapter. It facilitates use of previous designs, and allows design changes to be processed more quickly. Because CAD reduces the time necessary for many design tasks, it can also improve design by allowing designers to "try out" a dozen or a hundred different variations, where previously they might have been limited to building perhaps three or four prototype models. It also allows many drawings to be constructed more quickly, especially with an experienced CAD operator. Comparisons of design time with CAD range from 0.5 to 100 times as fast as manual systems, with 2 to 6 times as fast being typical.* For instance, Prototype and Plastic Mold Corp. in Middletown, Conn., is a small firm that uses CAD to design short-lived metal molds for plastic parts. The firm's president reported that designs could be produced with CAD roughly twice as fast as previously. For example, they received specifications for a plastic part mold by air express one Saturday morning, and planned to return the design drawings by air express that evening—a feat which, they reported, would have been impossible without CAD.**

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[7] S. B. Newell, A. J. de Geus, and R. A. Rohrer, "Design Automation for Integrated Circuits," *Science*, Apr. 29, 1983, pp. 465-471.

*Many of these estimates represent comparisons of the time necessary for a very narrowly defined task, and exclude time necessary for related tasks on a CAD system such as setting up the machine, manipulating files, or recovering from a machine failure.

**OTA site visit, Prototype and Plastic Mold Corp., Middletown, Conn., June 3, 1983. One scientist has pointed out that the time savings would be even more striking if Prototype and

Other applications of CAD, though not directly connected to manufacturing, include mapping, architectural drawing and design, graphics for technical publishing, and animation and special effects in cinematography.

Computer-Aided Manufacturing (CAM) Technologies

Computer-aided manufacturing (CAM) is a widely used term in industrial literature, and it has various meanings. Here it is defined simply as those types of programmable automation which are used primarily on the factory floor to help produce products. The following sections provide functional descriptions of four CAM tools: robots, numerically controlled machine tools, flexible manufacturing systems, and automated materials handling systems.

Robots

Robots are manipulators which can be programed to move workpieces or tools along various paths. Most dictionary definitions describe robots as "human-like," but industrial robots bear little resemblance to a human.*

There is some controversy over the definition of a robot. The Japan Industrial Robot Association, for example, construes almost any machine that manipulates objects to be a robot (essentially including the "hard automation" mentioned earlier), while the oft-quoted Robotic Industries Association (RIA) definition** emphasizes that the robot must be flexible, or relatively easily changed from one task to another. The RIA definition thus excludes preset part-transfer machines used for decades as a part of large-batch and mass-production systems, whose path can be changed only by mechanically reworking or rearranging the device. Also excluded are "manual manipulators" or "teleoperators"—devices directly controlled by a human such as those for remote handling of radioactive material.

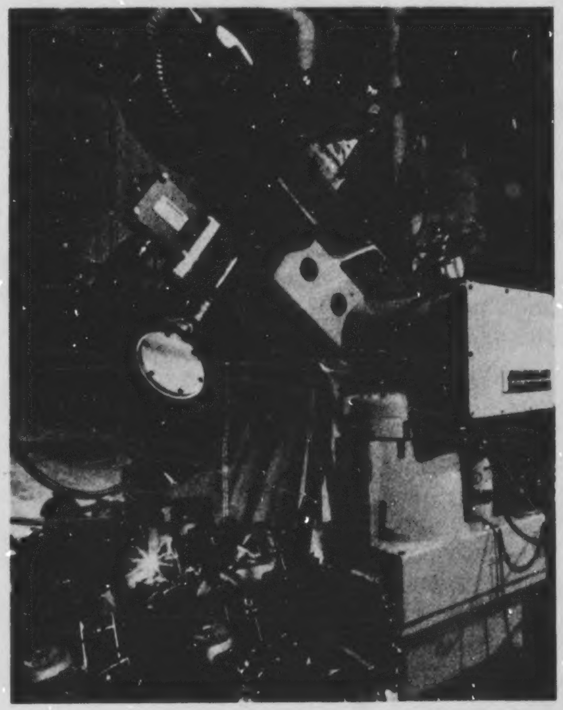

Photo credit: Cincinnati Milacron Corp.

A robot used for welding

As OTA observed in an earlier report on this subject,[9] industrial robots have a dual technological ancestry, emerging from: "1) industrial engineering automation technology, a discipline that stretches historically over a century; and 2) computer science and artificial intelligence* technology that is only a few decades old." Indeed, there is still a dichotomy

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Plastic Mold's staff could have transmitted the design information by telephone computer links; such activities have begun to be feasible within the last few years.

*In this sense the technical usage of the term "robot" differs from its dictionary definition (and from its roots in literature, in particular Karel Capek's 1923 novel, *R.U.R. (Rossum's Universal Robots) A Fantastic Melodrama.* (Garden City, N.Y.: Doubleday, Page & Co., 1923). A robot which resembled a human would be an "android," in robotics parlance. Such a machine has not been designed, and there does not appear to be substantial movement toward human-like robots (except, perhaps for motion pictures and other entertainment purposes). Later sections of this chapter will discuss adding certain anthropomorphic characteristics and skills to robots.

**RIA (a trade association of robot manufacturers, consultants, and users, formerly the Robot Institute of America) defines a robot as a "reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programed motions for the performance of a variety of tasks."

[9] *Exploratory Workshop on the Social Impacts of Robotics: Summary and Issues* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-BP-CIT-11, February 1982).

*Artificial intelligence research seeks to develop computer systems that can perform tasks which are ordinarily thought to require human intelligence.

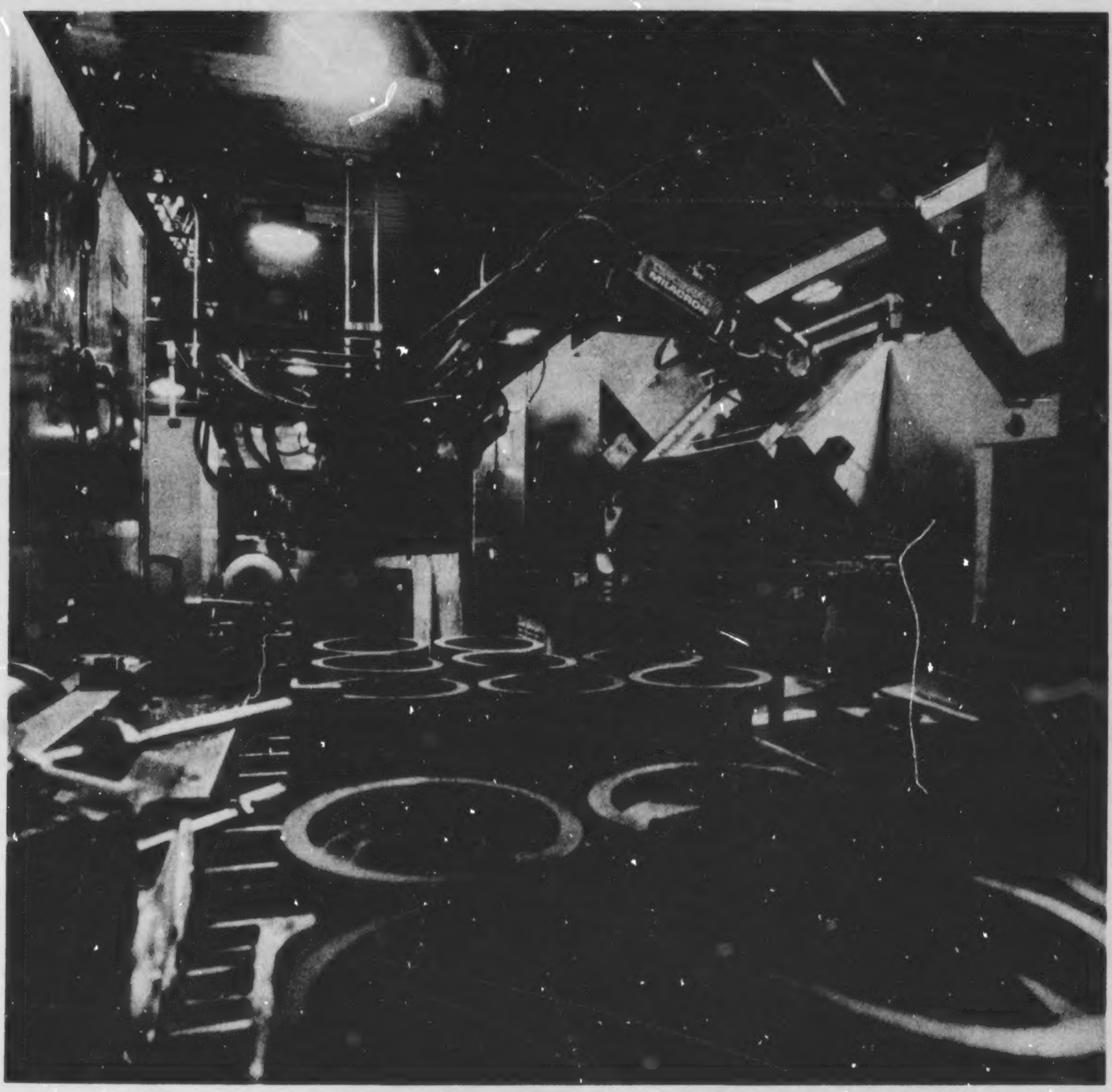


Photo credit: Cincinnati Milacron Corp.

Robot used for loading and unloading a machine tool

among experts regarding the applications and research directions for robotics. Some emphasize the need for anthropomorphic capabilities in robots such as "intelligence," vision, and mobility, while others view robots as simply a more versatile extension of other manufacturing tools.

While it is uncertain to what extent artificial intelligence researchers will succeed in developing intelligent machines in the next few decades, it is certain that robots currently available, and those likely to be available in the next decade, neither look like humans nor have more than a fraction of the dexterity, flexibility, or intelligence of humans. A more accurate term for these machines might be "programmable manipulator." Nevertheless it is clear that much of the great popular interest in robotics is rooted in the prevailing vision (or nightmare) of intelligent robots with human-like characteristics. Artificial intelligence will be discussed in more detail in the "Technical Trends and Barriers" section of this chapter.

How Robots Work.—There are three main parts of a typical industrial robot: the controller, manipulator, and end-effector. The controller consists of the hardware and software—usually involving a microcomputer or microelectronic components—which guides the motions of the robot and through which the operator programs the machine. The manipulator consists of a base, usually bolted to the floor, an actuation mechanism—the electric, hydraulic, or pneumatic apparatus which moves the arm—and the arm itself, which can be configured in various ways to move through particular patterns. In the arm, "degrees of freedom"—basically, the number of different joints—determine the robot's dexterity, as well as its complexity and cost. Finally, the end-effector, usually not sold as part of the robot, is the gripper, weld gun, or other tool which the robot uses to perform its task.

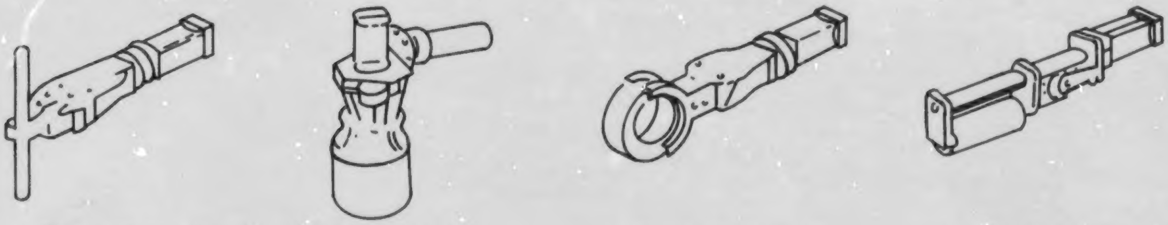
The structure, size, and complexity of the unit varies depending on the application and the industrial environment. Robots designed to carry lighter loads tend to be smaller, and operated electrically; many heavier units move their manipulator hydraulically. Some of the simpler units are pneumatic. Some of the heaviest material-handling robots and the newer light-assembly robots are arranged gantry-style, that is, with the manipulator hanging from an overhead support. A few robots are mobile to a limited degree, e.g., they can roll along fixed tracks in the floor or in their gantry supports.

Similarly, there is a great variety of end-effectors, particularly grippers, most of which are customized for particular applications. Grippers are available to lift several objects at once, or to grasp a fragile object without damaging it (see fig. 5).

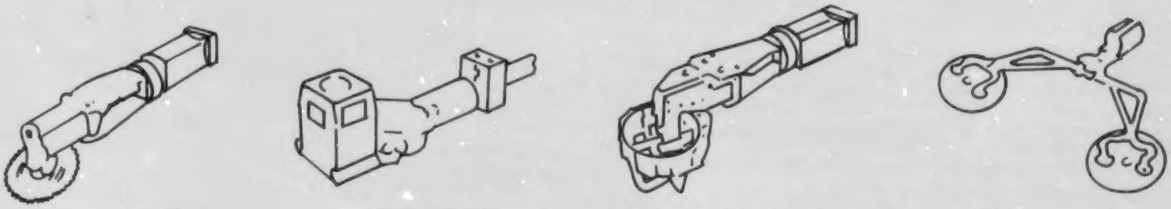
Programing.—There are essentially two methods of programing a robot. The most commonly used method is "teaching by guiding." The worker either physically guides the robot through its path, or uses switches on a control panel to move the arm. The controller records that path as it is "taught." Just beginning to emerge is "offline programing," where an operator writes a program in computer language at a computer terminal, and directs the robot to follow the written instructions.

Each method of programing has advantages that depend on the application. Teaching by guiding is the simplest and is actually superior for certain operations: spray painting is an example where it is useful to have the operator guide the robot arm through its path, because of the continuous, curved motions usually necessary for even paint coverage. However, teaching by guiding offers minimal ability to "edit" a path—i.e., to modify a portion of the path without re-recording the entire path. Offline programing is useful for several reasons: 1) production need not be stopped while the robot is being programed; 2) the factory floor may be an inhospitable environment for programing, whereas offline programing can be done at a computer terminal in an office; 3) as computer-aided manufacturing technologies become more advanced and integrated, they will increasingly be able to automatically generate robot programs from design and manufacturing data bases; and 4) an offline, written program can better accommodate more complex tasks, especially those in which "branching" is involved (e.g., "if the part is not present, then wait for the next cycle"). These branching decisions require some kind of mechanism by which the robot can sense its external environment. However, the vast majority of robotic devices are unable to sense their environment, although they may have internal sensors to provide feedback to their controller on the position of the arm joints.

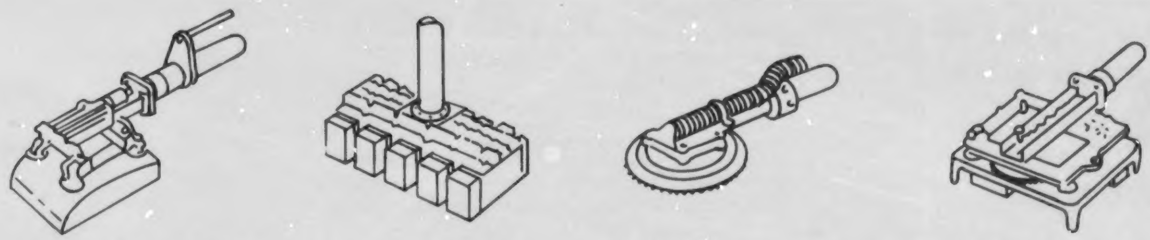
Figure 5.—Sample Robot Grippers



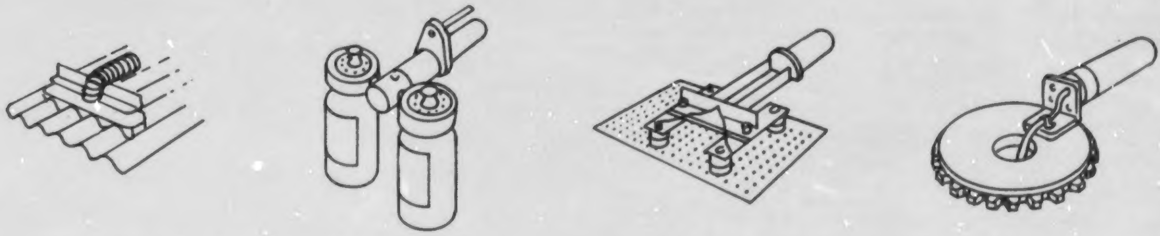
For small diameters Internal, 3 fingers Fitted to the diameter Fitted to the length



Internal For large objects For cast parts Vacuum, double



Vacuum, curved surface Vacuum, several parts Vacuum pad, several parts Vacuum, record player



Vacuum corrugated surface Balloon lifter, bottles Magnet lifter Magnet lifter

SOURCE: Tech Tran Corp., *Industrial Robots: A Summary and Forecast*, 1983.

Sensors.—Devices for sensing the external environment, while often used in conjunction with robots, are a growing technology in themselves. The simplest sensors answer the question, "Is something there or not?" For example, a light detector mounted beside a conveyor belt can signal when a part has arrived because the part breaks a light beam. Somewhat more complex are proximity sensors which, by bouncing sound off objects, can estimate how far away they are. The technology for these devices is fairly well-established. But the most powerful sensors are those which can interpret visual or tactile information; these have just begun to become practical.

Ideally, vision sensors could allow a robot system to respond to changes in its environment, and inspect products, as well as or better than a human could. However, using computers to process images from a video camera has proven to be an extraordinarily difficult programing task. Routine variations in lighting, the complexity of the everyday environment, common variations in shape or texture, and the difference between a 2-D camera image and a 3-D world all complicate the task of computer processing of a video image.

Other kinds of sensing devices, from proximity sensors to touch and force sensors, have received much less attention than machine vision, but they also could play an important role in the factory environment, particularly for assembly applications. Sensors will be discussed in greater detail later in the chapter.

Applications.—Table 6 displays some of the most recent robot use estimates. Figure 6 estimates the robot sales and total use in the United States for the next decade. Such statistics should be interpreted with caution, however. In particular, the number of robots in use is a highly imperfect measure of the level of automation and modernization in an industry or country. Process changes in manufacturing which increase productivity may or may not include robots. As one report on international use of robots observes:[9]

> It is also important that robots be viewed as part of the overall changes taking place in manufacturing concepts with the increasing diffusion of automated manufacturing equipment, including computer-aided manufacturing and computer-aided design systems. The impact of new production concepts, equipment and systems on production control and machine utilisation, inventory control and management efficiency will together have a much greater productivity impact than the industrial robot alone.

As noted earlier in this chapter, international comparisons of robot "populations" are also plagued by inconsistencies in the definition of a robot, particularly between the United States and Japan. Regardless of the definition of robot used, Japan leads the world in number of robots in use. The reasons for Japan's emphasis on robot technology include a historical shortage of labor, and a tendency to devote more engineering expertise to manufacturing processes than does the United States. In addition, the United States faced

Table 6.—Operating Robot Installations, End of 1982

Country	Number	Percent of total
Japan	31,900	66
United States	6,301	13
West Germany	4,300	9
Sweden	1,450	3
Italy	1,100	2
France	993	2
United Kingdom	977	2
Belgium	305	†
Poland	285	†
Canada	273	†
Czechoslovakia	154	†
Finland	98	†
Switzerland	73	†
Netherlands	71	†
Denmark	63	†
Austria	50	†
Singapore	25	†
Korea	10	†
Total	48,428	

†Less than 1 percent.

Note: This table does not include 9,000 "variable sequenced manipulators" which are included in the RIA's estimate for France. Statistics on robots differ because of differing definitions of a robot, because of different methodologies for collecting data, and because "operating robot installations" (as used in this table) may differ from "robot population," which includes some robots in laboratories and others not yet in use. A December 1983 study by the U.S. International Trade Commission, for example ("Competitive Position of U.S. Producers of Robotics in Domestic and World Markets") gives slightly different figures for robot population in the United States and West Germany (7,232 and 3,500, respectively).

SOURCE: Robot Institute of America, *Worldwide Robotics Survey and Directory*, 1983.

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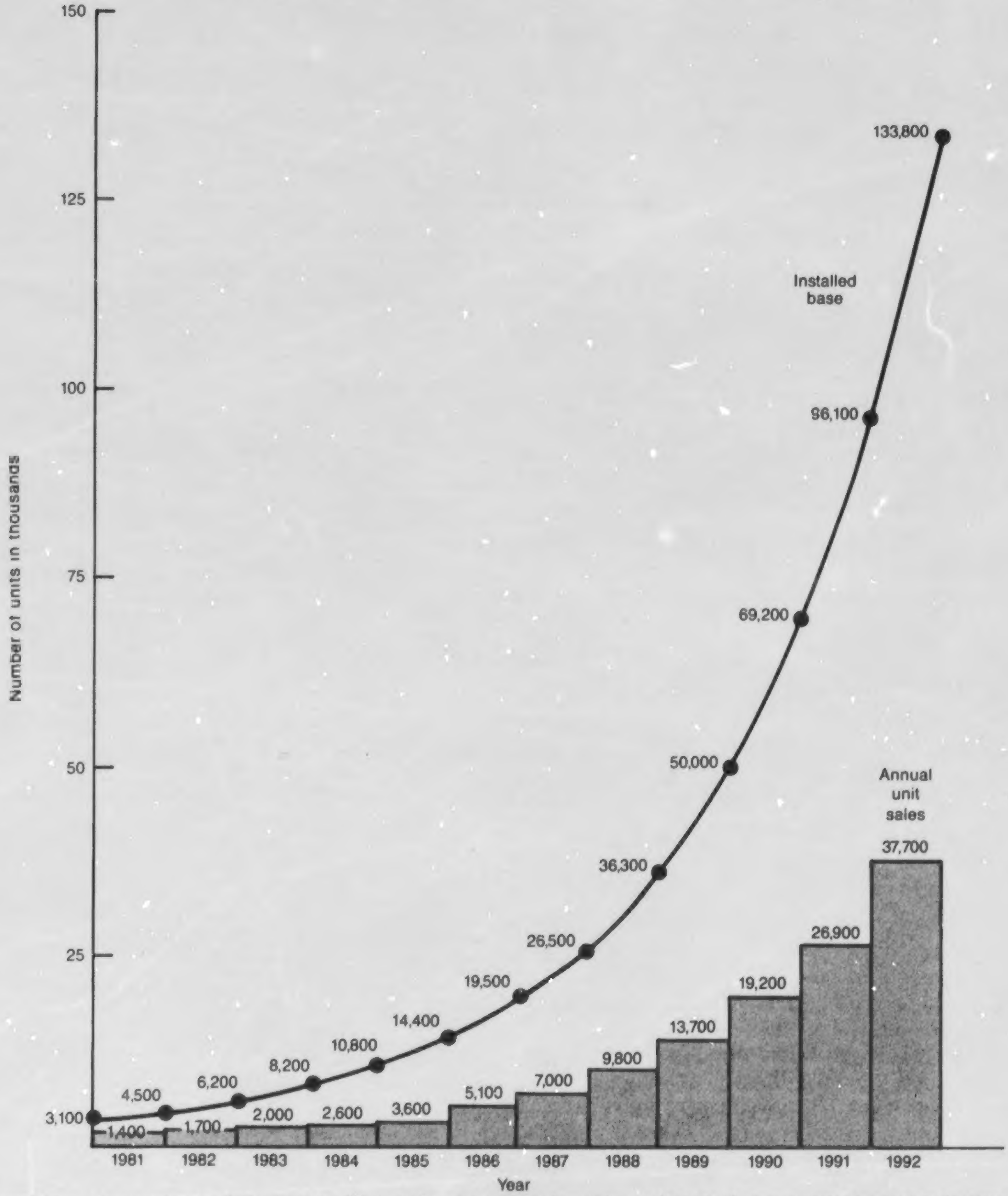
[9] OECD, "Robots: The Users and the Makers." *The OECD Observer*, July 1983.

Figure 6.—Actual and Projected U.S. Annual Robot Sales and Installed Base Through 1992



NOTE: The projections above are highly speculative. Robot sales have not grown nearly as fast as most industry observers expected, and one industry analyst suggests that the above figures may be as much as 30 to 50 percent too high. (E. Lustgarten, Vice President, Paine, Webber, Mitchell, Hutchins, Inc., personal communication, Feb. 7, 1984). On the other hand, robot vendors and the Robotic Industries Association still believe that a tremendous upsurge in robot sales is forthcoming, and the projections above may even be too low. (L. Lachowicz, Robotic Industries Association, personal communication, Feb. 7, 1984). See ch. 7 for further discussion of the robot industry and its prospects.

SOURCE: Tech Tran Corp., *Industrial Robots: A Summary and Forecast*, 1983.

labor surpluses throughout the 1970's, which tended to induce manufacturers to use labor instead of equipment in production. Chapter 9 will discuss international comparisons in more detail.

Sophistication in reprogrammability, as well as size and degrees of freedom, are some of the key cost factors for an industrial robot. A simple "pick-and-place" machine with 2 or 3 degrees of freedom costs roughly $5,000 to $30,000, while more complex programmable models, often equipped with microcomputers, cost approximately $25,000 to $90,000 and up.[10]

Table 7 lists some of the potential applications for industrial robots. Many of the first applications of robots have been for particularly unpleasant or dangerous tasks. One of the earliest uses, for example, was for loading and unloading die-casting machines, a hazardous and unpleasant task because of the extreme heat. The best-known uses, however, have been in spray painting and spot welding in the auto and related industries. In these applications, robots have proven to be useful for performing particularly hazardous and monotonous jobs while offering enough flexibility to be easily adapted to changes in car models or body styles.

There are a number of motivations behind the use of robots on such unpleasant jobs. Improvement of job conditions (and, consequently, worker morale) is one of them, though it may not be the primary one. Such jobs often have high worker turnover and inconsistent product quality because of their unpleasantness. Also, compliance with the occupational safety and health regulations that protect people performing these tasks adds to production costs. In addition, tasks like spray painting and spot welding are often relatively easy to automate because the paths the robot is to follow are predictable, and the tasks are repetitive and require little sensing capability.

Table 7.—Examples of Current Robot Applications

Material Handling:
- Depalletizing wheel spindles into conveyors
- Transporting explosive devices
- Packaging toaster ovens
- Stacking engine parts
- Transfer of auto parts from machine to overhead conveyor
- Transfer of turbine parts from one conveyor to another
- Loading transmission cases from roller convveyor to monorail
- Transfer of finished auto engines from assembly to hot test
- Processing of thermometers
- Bottle loading
- Transfer of glass from rack to cutting line

Machine loading/unloading:
- Loading auto parts for grinding
- Loading auto components into test machines
- Loading gears onto CNC lathes
- Orienting/loading transmission parts onto transfer machines
- Loading hot form presses
- Loading transmission ring gears onto vertical lathes
- Loading of electron beam welder
- Loading cylinder heads onto transfer machines
- Loading a punch press
- Loading die cast machine

Spray painting:
- Painting of aircraft parts on automated line
- Painting of truck bed
- Painting of underside of agricultural equipment
- Application of prime coat to truck cabs
- Application of thermal material to rockets
- Painting of appliance components

Welding:
- Spot welding of auto bodies
- Welding front-end loader buckets
- Arc welding hinge assemblies on agricultural equipment
- Braze alloying of aircraft seams
- Arc welding of tractor front weight supports
- Arc welding of auto axles

Machining:
- Drilling aluminum panels on aircraft
- Metal flash removal from casings
- Sanding missile wings

Assembly:
- Assembly of aircraft parts (used with auto-rivet equipment)
- Riveting small assemblies
- Drilling and fastening metal panels
- Assembling appliance switches
- Inserting and fastening screws

Other:
- Application of two-part urethane gasket to auto part
- Application of adhesive
- Induction hardening
- Inspecting dimensions on parts
- Inspection of hole diameter and wall thickness

SOURCE: Tech Tran Corp., *Industrial Robots: A Summary and Forecast*, 1983.

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[10] E. Lustgarten, Vice President, Paine, Webber, Mitchell, Hutchins, Inc., personal communication.

While spot welding, spray painting, and loading/unloading applications have been the primary uses for robots, increasing sophistication in programmability and in sensing is enabling applications such as arc welding and assembly.

As an example of such an application, a welder at Emhart Corp.'s United Shoe Manufacturing plant in Beverly, Mass., uses a robot to arc-weld frames for shoemaking machinery* (see photo). He welds several dozen identical frame units at a time; each frame unit requires perhaps a dozen 2-inch welds to attach reinforcing bars to a steel sheet. The welder clamps the first sheet and reinforcing bars onto a table. Using directional buttons on a "teach pendant"—a portable panel attached to the robot's controller—he directs the robot to the spot where it is to begin the first weld. He pushes a button to record that location. Still using the teach pendant, he moves the robot to the end of the weld and records that location. Then he presses a button which instructs the machine to "weld a straight line from the first point to the second." After repeating this process for each of the dozen welds, he gives the command for the robot to begin welding, and the robot follows the path it has been "led through"—this time with its welding gun on. For each subsequent identical frame unit, all that is required is to clamp down the parts in the same location as the original set on which the machine was

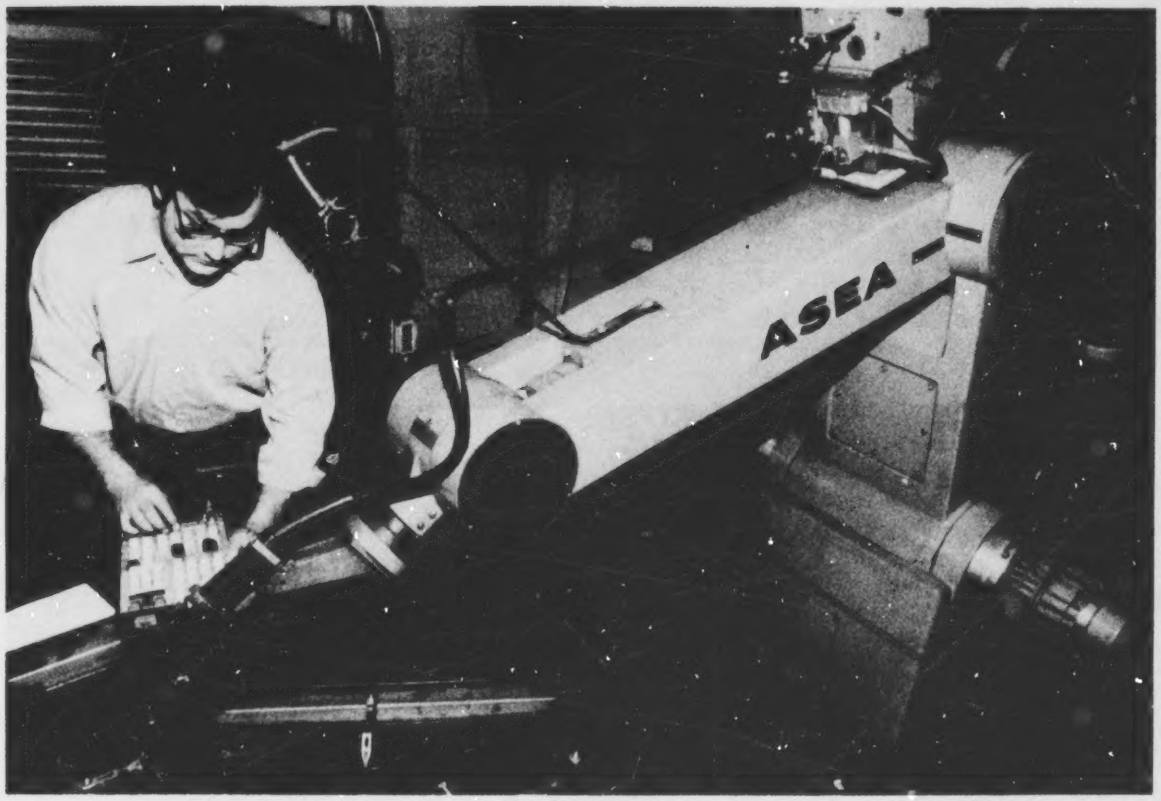

Photo credit: Emhart Corp.

Welder Pete Bolger at Emhart's United Shoe Manufacturing Plant uses a "teach pendant" to program a robot to weld parts of a metal frame, below left. After the robot is taught the correct steps, it can repeat those steps with its welding gun on, while the operator can set up another frame on an adjacent table or perform other duties

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*OTA site visit, Emhart Corp., United Shoe Manufacturing Plant, Beverly, Mass., June 28, 1983.

"taught," signal the machine to begin, and then inspect the welds after the machine completes its program. The robot controller can store several programs, so that the operator can use the robot to weld different types of frames in any order he chooses, as long as he sets up the steel plates and reinforcing bars in the appropriate positions.

Note that this application of a robot for arc welding does not use sensors, even though there has been extensive work done on developing vision sensors that allow the robot to "see" the seam formed by the two pieces of metal, and to follow it automatically. For the fairly simple, straight-line applications at Emhart, sensors are not necessary. However, if the frame units were out of position by a half-inch, the welding robot would put a useless blob of metal where it expected the joint to be. If a clamp was in the way of a programed weld, the robot would attempt to weld through the clamp, damaging the clamp and itself in the process.

The advantages of robots depend on whether one is comparing them to hard automation devices or to human workers. Clearly, the flexibility and programmability of robots is prominent in the first case, while in comparison with humans the advantages are likely to be the robot's greater consistency, endurance, and ability to tolerate hostile environments.

The disadvantages of robots also depend on whether they are compared with other automation or humans. In the former case, robotic devices are sometimes more expensive than a hard automation device which is not programable, and they are not as fast—a typical robot moves about as fast as a human, while dedicated automatic part-transfer devices can operate at considerably greater speed. The clear advantage of human workers over robots, on the other hand, is in situations where extensive sensing, judgment, or intelligence is required, and/or where situations change so frequently that the expense of programing a robot is uneconomical. For these reasons it is often suggested that humans, robots, and hard automation devices are best suited for low, medium, and high production volumes, respectively, although there are many exceptions to this—e.g., automotive spot welding. Each situation must be evaluated individually.

The design of automated production processes involves determining which tasks are most suitable for a machine, and which are most suitable for a human. Several technology experts have argued that some manufacturers' visions of robots as replacements for human workers will prevent the best allocation of tasks between human and machine. One researcher argues:

> A robot is a machine. It should be designed, controlled, and operated as a machine. Any attempt to emulate human behavior with a robot is a misdirection. Take, for example, the task of turning a bolt. A human turns down a bolt in roughly half-revolution increments. At today's state-of-the-art, most robots are constrained to perform the task in the same way. But robots need not be constrained the way humans are. The most distal axis of a robot should be capable of continuous rotation. The primary advantage that robots will have in the manufacturing market of the future will be based not on their ability to mimic humans, but on their abilities to perform tasks in ways which humans cannot.[11]

General-purpose robots are already evolving toward special-purpose programmable devices for a particular task (e.g., assembly machines, painting machines), and this evolution may continue so that few robots in the future look like the general-purpose "arm" of today.

Though they will not be covered in detail here, robotics technology has a wide range of nonmanufacturing uses including handling of radioactive material, mining, undersea exploration, and aids for the handicapped.[12]

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[11] W. P. Seering, "Directions in Robot Design," *Transactions of the ASME,* March 1983, pp. 12-13.

[12] See, for example, T. N. Sofyanos and T. B. Sheridan, *An Assessment of Undersea Teleoperators,* Sea Grant College Program, Massachusetts Institute of Technology, June, 1980; A. Seireg and J. Grundman, "Design of a Multitask Exoskeletal Walking Device," *Biomechanics of Medical Devices,* D. N. Ghista (ed.) (New York: Marcel Dekker Inc., 1981), pp. 569-639.

Numerically Controlled Machine Tools

Numerically controlled, or NC, machine tools are devices which cut a piece of metal according to programed instructions about the desired dimensions of a part and the steps for the machining process. They consist of a machine tool, specially equipped with motors to guide the cutting process, and a controller which receives numerical control commands.

The U.S. Air Force developed NC technology in the 1940's and 1950's, in large part to help produce complex parts for aircraft which were difficult to make reliably and economically with a manually guided machine tool.

How They Work.—Machine tools for cutting and forming metal are the heart of the metalworking industry. Using a conventional, manual machine tool, a machinist guides the shaping of a metal part by hand. He or she moves either the workpiece or the head of the cutting tool to produce the desired shape of the part. The machinist controls the speed of the cut, the flow of coolant, and all other relevant aspects of the machining process.

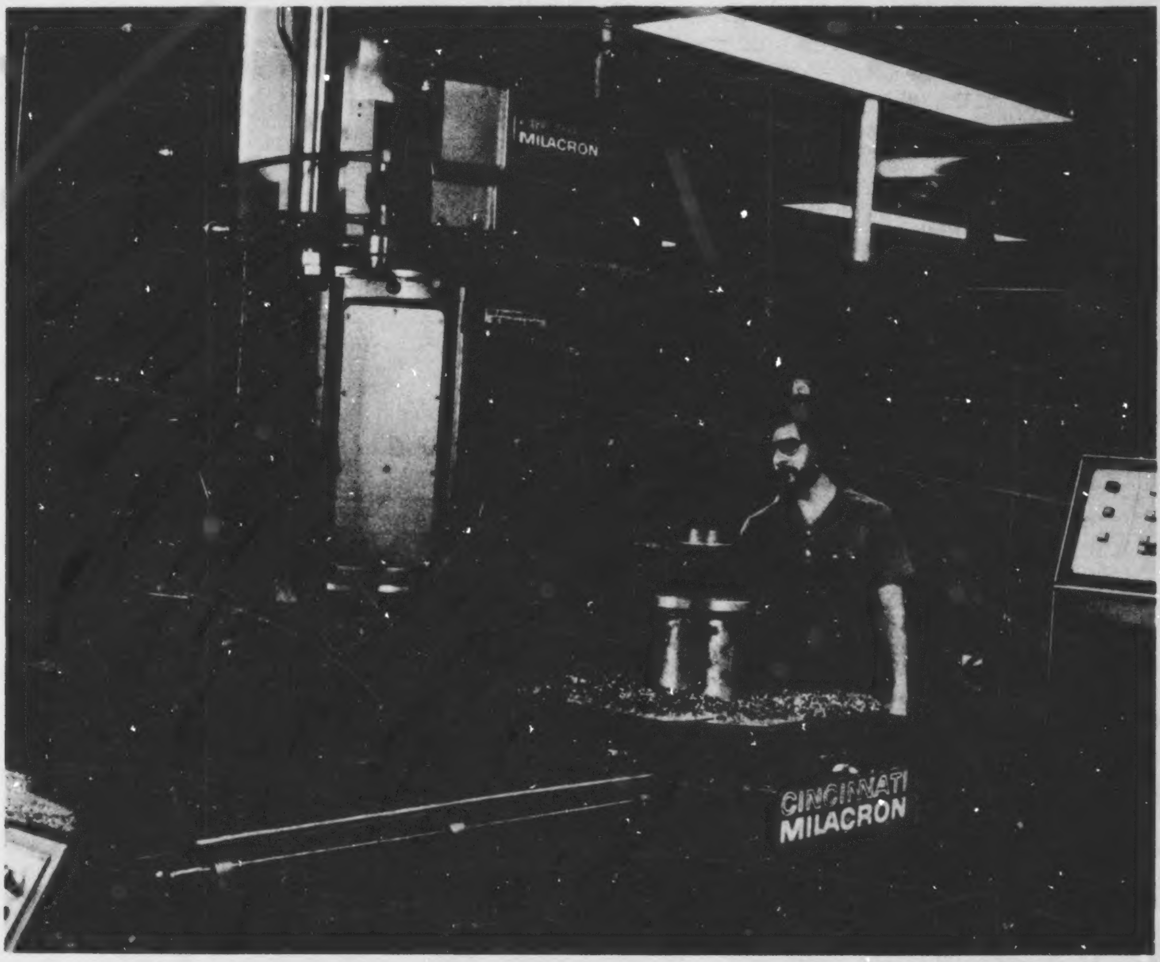


Photo credit: Cincinnati Milacron Corp.

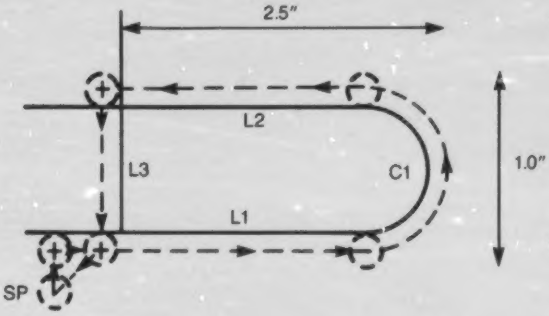
An operator supervises a large, computerized numerically controlled (CNC) machine tool. The minicomputer which controls the tool is at right; at left additional cutting tools are loaded into an automatic tool changing device

In ordinary NC machines, programs are written at a terminal which, in turn, punches holes in a paper or mylar plastic tape. The tape is then fed into the NC controller. Each set of holes represents a command, which is transmitted to the motors guiding the machine tool by relays and other electromechanical switches. Although these machines are not computerized, they are **programmable** in the sense that the machine can easily be set to making a different part by feeding it a different punched tape; and they are **automated** in that the machine moves its cutting head, adjusts its coolant, and so forth, without direct human intervention. However, most of these machines still require a human operator, though in some cases there is one operator for two or more NC machine tools. The operator supervises several critical aspects of the machine's operation:

1. he or she has override control to modify the programed speeds (rate of motion of the cutting tool) and feeds (rate of cut) (see fig. 4). These rates will vary depending on the batch of metal used and the condition of the cutting tool;
2. he or she watches the quality and dimensions of the cut, and listens to the tool, replacing worn tools (ideally) before they fail; and
3. he or she monitors the process to avoid accidents or damage—e.g., a tool cutting into a misplaced clamp, or a blocked coolant line.

Typically, NC programs are written in a language called APT (Automatically Programed Tools), which was developed during the initial Air Force research on NC (see fig. 7 for a sample of an APT program). A number of modified versions of APT have been released in the last decade, and some of these are easier to use than the original. But the essential concept and structure of the numerical codes has remained the same. In large part because of the momentum it gained from its initial DOD support, APT has become a de facto standard for NC machine tools.

Figure 7.—Sample APT Computer Program



The path of the center of the cutter is shown as it moves about the perimeter of the part.

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(1)             PARTNO FLAT PLATE NO 12345678
(2)             MACHIN/MODEL PTX
(3)             CLPRNT
(4)             CUTTER/.25
(5)             FEDRAT/10
(6)     SP  =   POINT/ - .5, - .5,1
(7)     P1  =   POINT/0,0,0
(8)     L1  =   LINE/P1, ATANGL,0
(9)     C1  =   CIRCLE/2,.5,.5
(10)    P2  =   POINT/0,1,0
(11)    L2  =   LINE/P2,PARLEL,L1
(12)    L3  =   LINE/P2,PERPTO,L1
(13)            FROM/SP
(14)            GO/TO,L1
(15)            GORGT/L1,TANTO,C1
(16)            GOFWD/C1,TANTO,L2
(17)            GOFWD/L2,PAST,L3
(18)            GOLFT/L3,PAST,L1
(19)            GOTO/SP
(20)            FINI
```

The APT computer program, above, directs a machine tool to cut around the perimeter of a flat metal part with a semicircular end (see top diagram). In the program, the first line identifies the part, and line (2) calls out the postprocessor for the machine/control combination that is to machine the part. The postprocessor is that part of the computer software program that tailors the tape instructions for the particular machine/control combination. Line (3) notes that the computer is to print out the coordinates of all the straight-line moves of the cutter. Line (4) notes that the cutter is to have a diameter of 0.25 inches. Line (5) describes the feed rate in inches per minute. Lines (6) through (12) describe the geometry of the part. Lines (13) through (19) are motion statements and describe the path of the cutter. Line (20) ends the part program.

SOURCE: J. J. Childs, *Principles of Numerical Control* (New York: Industrial Press, 1982, pp. 134-135.

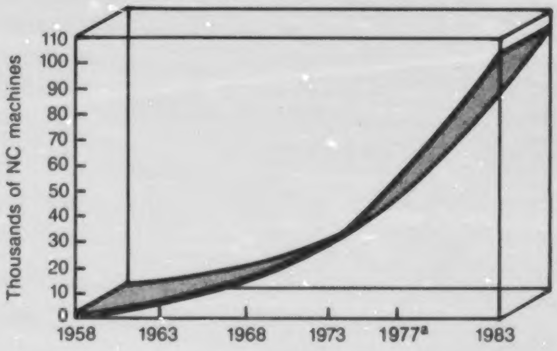
Since 1975, machine tool manufacturers have begun to use microprocessors in the controller, and some NC machines come equipped with a dedicated minicomputer. Those called computerized numerically controlled (CNC) tend to be equipped with a screen and keyboard for writing or editing NC programs at the machine. Closely related to CNC is direct numerical control (DNC), in which a larger mini- or mainframe computer is used to program and run more than one NC tool simultaneously. As the price of small computers has declined over the past decade, DNC has evolved both in meaning and concept into distributed numerical control, in which each machine tool has a microcomputer of its own, and the systems are linked to a central controlling computer. One of the advantages of such distributed control is that the machines can often continue working for some time even if the central computer "goes down."

In all types of NC machine tools the machining processes are essentially the same—the difference is in the sophistication and location of the controller. CNC controllers allow the operator to edit the program at the machine, rather than sending a tape back to a programer in a computer room for changes. In addition, by avoiding the use of paper or mylar tape, CNC and DNC machines are substantially more reliable than ordinary NC machines. The tape punchers and readers and the tape itself have been notorious trouble spots. CNC and DNC machines, through their computer screens, may also offer the operator more complete information about the status of the machining process.

Some NC tools are equipped with a feature called "adaptive control," which tries to automatically optimize the rates of cut to produce the part as fast as possible, while avoiding tool failure. As yet, there has been limited success with these devices.

Applications.—The diffusion of NC technology into metalworking industry proceeded very slowly in the 1950's and 1960's, though it has accelerated somewhat over the past 10 years. Figure 8 and table 8 detail the U.S. population of machine tools. Numerically controlled machine tools represent only 4.7 percent of the total population,[13] although this figure may be somewhat misleading: the newer, NC machine tools tend to be used more than the older equipment, and firms often keep old equipment even when they buy new machines. Some industry experts have estimated that as many as half of the parts made in machine shops are made using NC equipment. Nevertheless, the applications still tend to be concentrated in large firms and in smaller subcontractors in the aerospace and defense industries.

Figure 8.—Total Number of Numerically Controlled Machine Tools in U.S. Metalworking



[a] 12th Inventory data collected over 3 years, 1976 to 1978.

SOURCE: 13th American Machinist Inventory, *American Machinist*, November 1983.

Table 8.—Estimated Total Machine Tools in the United States

	Total units	Metal-cutting	Metal-forming
Metalworking	2,192,754	1,702,833	489,921
Other industries	380,000	275,000	105,000
Training	74,000	70,000	4,000
In storage and surplus	250,000	200,000	50,000
Total	2,896,754	2,247,833	648,921

SOURCE: 13th Annual American Machinist inventory and estimates, *American Machinist*, November 1983.

Two examples from OTA's case studies illustrate a range of uses for NC machine tools. A Connecticut machine shop with 48 employees on the shop floor began using numerical control technology around 1966, and now uses 23 NC machines to produce contracted parts for the electronics and aircraft industries. By contrast, one of the NC machine shops at a large commercial aerospace manufacturer occupies 471,000 square feet—about the size of 18 football fields—and includes 110 NC and CNC machine tools, as well as 230 conventional machine tools.[14]

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[13] "The 13th *American Machinist* Inventory of Metalworking Equipment 1983," *American Machinist*, November 1983, pp. 113-144.

The U.S. machine tool population is significantly older than that of most other countries (see table 9), and this situation, suggesting relatively low levels of capital investment, has been a source of concern for many in industry and government. In 1983, for the first time in several decades, the percentage of metalcutting tools less than 10 years old increased by 3 percent, although the percentage of metalforming tools less than 10 years old remains at an all-time low of 27 percent.[15]

DOD has encouraged diffusion of NC technology, which has moved beyond the aerospace industry—although not nearly as fast as most observers expected. There are several reasons for the relatively slow diffusion of NC technology. They include high capital cost for an NC machine (perhaps $80,000 to $150,000 and up, as opposed to $10,000 to $30,000 for a conventional machine tool).[16] In addition, the successful application of NC machine tools requires technical expertise that is in short supply in many machine shops. Training is a problem, as some users report requiring as much as 2 years "to get an NC programer up to speed."[17] Small machine shops typically do not have the resources or expertise to train staff to use or maintain computerized equipment. Finally, "APT proved to be too complicated for most users outside the aerospace industry. . . . Most machine jobs could be specified in a considerably less complex world."[18]

However, intricate shapes such as those now found in the aerospace industry are nearly impossible for even the most experienced machinist using conventional machine tools. With NC, the parts can be more consistent because the same NC program is used to make the part each time it is produced. A manually guided machine tool is more likely to produce parts with slight variations, because the machinist is likely to use a slightly different procedure each time he or she makes a part. This may not be a problem for one-of-a-kind or custom production, but can cause headaches in batch production. The advantages in consistency due to NC are seen by many manufacturers as an increase in their control over the machining process.

NC machines tend to have a higher "throughput" than conventional machine tools, and hence are more productive. They are operating (i.e., cutting metal) more of the time than a conventional machine tool because all the steps are established before the machining begins and are followed methodically by the machine's controller. Further, on a complex part that takes more than one shift of machining on a conventional machine tool, it is very difficult for a new machinist to take over where the first left off. The part may remain clamped to the machine and the part and machine tool lie idle until the original machinist returns. On NC machines, operators can substitute for each other relatively easily, allowing the machining to continue uninterrupted.

As discussed previously, the capability of guiding machine tools with numeric codes opens up possibilities for streamlining the steps between design and production. The geometric data developed in drawing the product on a CAD system can be used to generate the NC program for manufacturing the product.

Flexible Manufacturing Systems

A flexible manufacturing system (FMS) is a production unit capable of producing a range of discrete products with a minimum of manual intervention. It consists of production equipment workstations (machine tools or other equipment for fabrication, assembly, or treatment) linked by a materials-handling system to move parts from one workstation to

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[14] OTA work environment case studies.

[15] "The 13th *American Machinist* Inventory of Metalworking Equipment 1983," *American Machinist*, November 1983.

[16] E. Lustgarten, Vice President, Paine, Webber, Mitchell, Hutchins, Inc., personal communication.

[17] A. M. Greene, "Is It Time for a New Approach to NC Programming?" *Iron Age*, Sept. 24, 1982, p. 83. The need for substantial training applies not only to NC machine tools but to virtually all PA devices.

[18] Industry and Trade Strategies, unpublished paper prepared for OTA, April 1983, p. 28.

Table 9.—Age of Machine Tools in Seven Industrial Nations

		Metalcutting machines						Metalforming machines					
	Year	Units	0-2 yr	0-4 yr	0-9 yr	≥ 15 yr	≥ 20 yr	Units	0-2 yr	0-4 yr	0-9 yr	≥ 15 yr	≥ 20 yr
United States	83	1,703,000	—	14%	34%	—	32%	490,000	—	9%	18%	—	37%
Canada	78	149,400	—	—	41	—	37	61,400	—	—	23	—	26
Federal Republic of Germany	80	985,000	—	15	34	48%	—	265,000	—	15	34	48%	
France	80	584,000	—	16	35	—	32	177,000	—	16	35	—	32
Italy	75	408,300	—	—	41[c]	—	29[e]	133,000	—	—	29[c]	—	25[e]
Japan	81	707,000	15%	—	35[b]	37[d]	—	211,000	18%	—	41[b]	31[d]	—
United Kingdom	82	627,900	—	41[a]	—	—	27	146,800	—	48[a]	—	—	28

[a]0-5 years old; [b]0-7 years old; [c]0-8 years old; [d]13 years old and up; [e]18 years old and up.

SOURCE: 13th American Machinist Inventory, *American Machinist*, November 1983. (Note: *American Machinist* used a variety of foreign sources for this table).

another, and it operates as an integrated system under full programmable control.[19]

An FMS is often designed to produce a family of related parts, usually in relatively small batches—in many cases less than 100, and even as low as one. Most systems appropriately considered to be an FMS include at least four workstations, and some have up to 32. Smaller systems of two or three machine tools served by a robot, which are sometimes called flexible manufacturing systems, are more appropriately termed "machining cells."

How an FMS Works.—Using NC programs and (often) computer-aided process planning, workers develop the process plan (i.e., the sequence of production steps) for each part that the FMS produces. Then, based on inventory, orders, and computer simulations of how the FMS could run most effectively, the FMS managers establish a schedule for the parts that the FMS will produce on a given day. Next, operators feed the material for each part into the system, typically by clamping a block of metal into a special carrier that serves both as a fixture to hold the part in place while it is being machined, and as a pallet for transporting the workpiece. Once loaded, the FMS essentially takes over. Robots, conveyors, or other automated materials handling devices transport the workpiece from workstation to workstation, according to the process plan. If a tool is not working, many FMSs can reroute the part to other tools that can substitute.

Machine tools are not the only workstations in an FMS; other possible stations include washing or heat-treating machines, and automatic inspection devices. While most current FMSs consist of groups of machine tools, other systems anticipated or in operation involve machines for grinding, sheet metal working, plastics handling, and assembly.

The amount of flexibility necessary to deserve the label "flexible" is arguable. Some FMSs can produce only three or four parts of very similar size and shape—e.g., three or four engine blocks for different configurations of engines. One FMS expert argues, however,

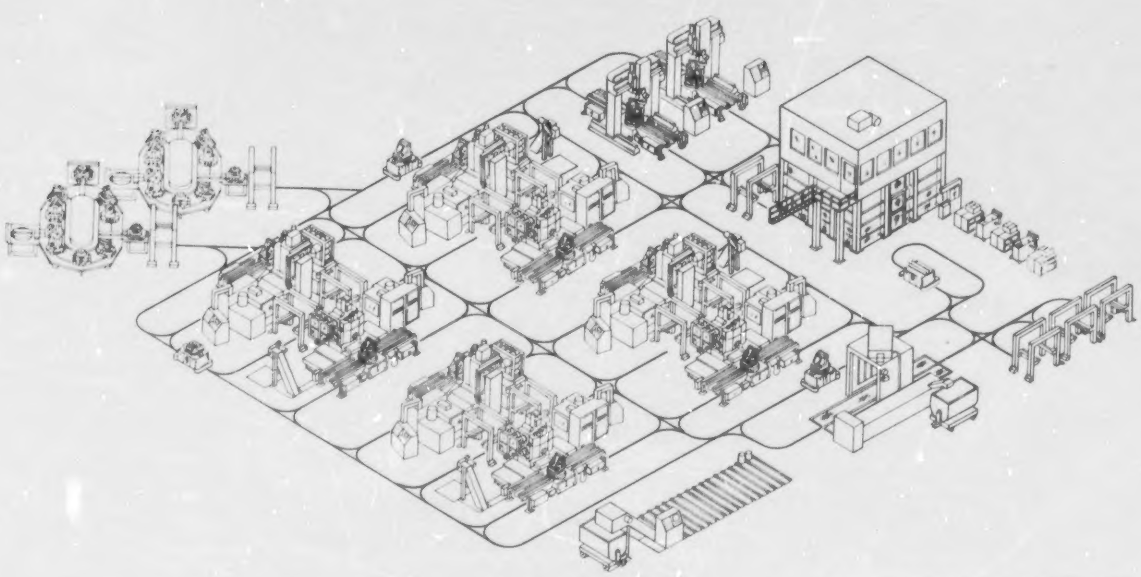

Illustration credit: Cincinnati Milacron Corp.

Schematic diagram of an FMS for producing aircraft parts. The lines indicate paths of automatic devices which bring workpieces to the machines

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[19] M. E. Merchant, personal communication, Oct. 12, 1983. Adapted from a definition developed by the International Institution for Production Engineering Research.

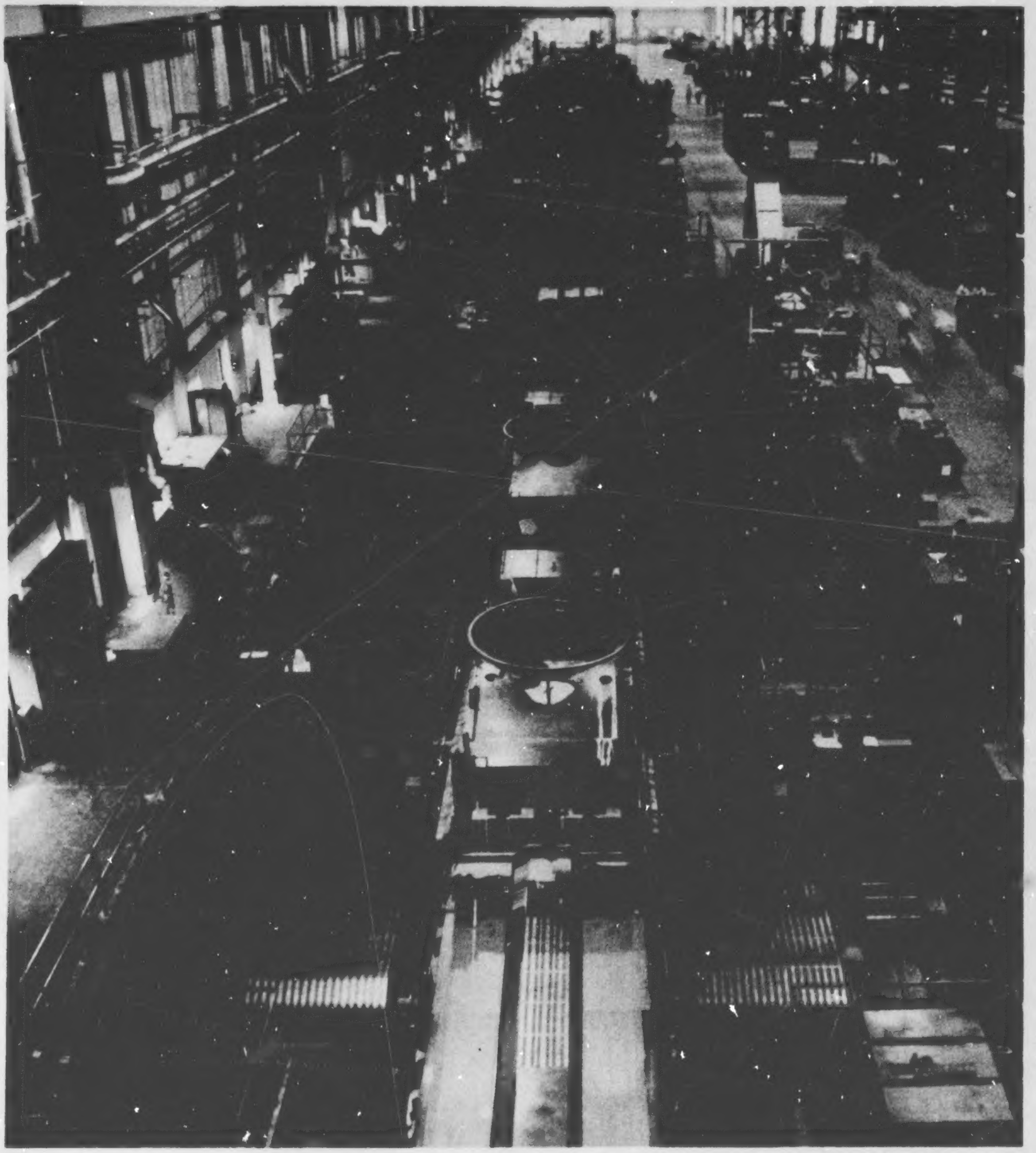

Photo credit: Cincinnati Milacron Corp.

An FMS system for tank parts

that in the current state of the technology, a system that cannot produce at least 20 to 25 different parts is not flexible. Indeed, some are being designed to manufacture up to 500 parts.[20]

The essential features that constitute a workable "part family" for an FMS are:

- *A common shape.*—In particular, prismatic (primarily flat surfaces) and rotational parts cannot be produced by the same set of machines.
- *Size.*—An FMS will be designed to produce parts of a certain maximum size, e.g., a 36-inch cube. Parts larger or much smaller than that size cannot be handled.
- *Material.*—Titanium and common steel parts cannot be effectively mixed, nor can metal and plastic.
- *Tolerance.*—The level of precision necessary for the set of parts must be in a common range.

Applications.—For a manufacturer with an appropriate part family and volume to use an FMS, the technology offers substantial advantages over stand-alone machine tools. In an ideal FMS arrangement, the company's expensive machine tools are working at near full capacity. Turnaround time for manufacture of a part is reduced dramatically because parts move from one workstation to another quickly and systematically, and computer simulations of the FMS help determine optimal routing paths. Most systems have some redundancy in processing capabilities and thus can automatically reroute parts around a machine tool that is down. Because of these time savings, work-in-process inventory can be drastically reduced. The company can also decrease its inventory of finished parts, since it can rely on the FMS to produce needed parts on demand.

Finally, FMS can reduce the "economic order quantity" for a given part—the batch size necessary to justify setup costs. When a part has been produced once on an FMS, setup costs for later batches are minimal because process plans are already established and stored in memory, and materials handling is automatic. In the ultimate vision of an FMS, the machine could produce a one-part batch almost as cheaply as it could produce 1,000, in cost per unit. In practice there are unavoidable setup costs for a part and a one-part batch is uneconomical. Nevertheless, the FMS's capability to lower the economic order quantity is particularly useful in an economy in which manufacturers perceive an increased demand for product customization and smaller batch sizes.*

A Midwestern agricultural equipment manufacturer, for example, uses an FMS to machine transmission case and clutch housings for a family of tractors (see photo). They had considered "hard automation"—a transfer line—to manufacture the parts, but expected

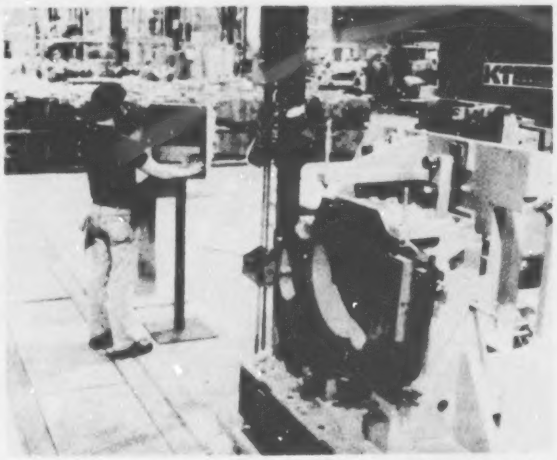

Photo credit: Deere & Co.

A worker obtains status information from a computer terminal at one of the workstations of an FMS for producing agricultural equipment a new generation of transmissions within 5 years, which would render the transfer line obsolete. They chose an FMS instead because it could be more easily adapted to other products. In the system, a supervisory computer controls 12 computerized machining centers and a system of chain-driven carts which shuttle the fixtured parts to the appropriate machines. The supervisory computer automatically routes parts to those machines with the shortest queue of workpieces waiting, and can reroute parts to avoid a disabled machine tool. About a dozen employees operate and maintain the system during the day shift, and there are even fewer people on the other two shifts. The system is designed to produce nine part types in almost any sequence desired. (Thus, it is rather inflexible according to the current state of the art.) It was, in fact, one of the earliest FMSs of substantial size to be designed. It was ordered in 1978, but not fully implemented until 1981.[21]

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[20] B. Johoski, Manager, Manufacturing Systems Division, Cincinnati Milacron Corp., interview, Aug. 16, 1983.

*In defense production, several examples of the very high cost of spare parts have come to light. In part because the set up cost for producing parts is so high, the Pentagon's contractors may charge thousands of dollars for producing one or two small parts. The traditional solution to this problem is to make spare parts when the original equipment is bought, and keep the spares on hand. However, studies indicate that more than 95 percent of those spare parts are never used. An FMS could substantially reduce the cost for making a small number of parts because once a part has been made on the system and the tooling and production routing already established, setup costs are relatively low.

Another example of FMS application is a system operating at Messerschmitt-Bolkow-Blohm's plant in Augsburg, West Germany, to manufacture the center section of Tornado fighter planes at a rate of about 10 per month. The system includes 28 NC machine tools, automatic systems for cutting-tool changing and workpiece transport, and complete computer control. One observer reports:

> The system has demonstrated remarkable efficiencies. They find that the machines in the system are cutting metal, on the average, about 75 percent, or more, of the time—i.e., machine utilization is 75 percent better. Lead time for production of a Tornado is only 18 months, compared to about 30 months for planes produced by more conventional means. The system reduced the number of NC machines required (compared to doing the same job with stand-alone NC machines) by 52.6 percent, required personnel by 52.6 percent, required floor place [sic] by 42 percent, part through-put time by 25 percent, total production time by 52.6 percent, tooling cost by 30 percent, total annual costs by 24 percent and capital investment costs by 10 percent.[22]

Finally, a Fanuc Ltd. factory near Mt. Fuji in Japan has received a great deal of attention and is similarly impressive. The factory produces industrial robots and various CNC tools. It has two automated storage and retrieval systems (these are described in the next section) as well as an automated materials handling system to deliver materials to workstations. Automatic pallet changers and robots are used to load and unload machine tools from the automatic materials handling vehicles, and the plant makes extensive use of unmanned machining at night. The 29 machining centers are attended by 19 workers during the day shift, while at night no one is on the machining floor, and one worker monitors the operation from a control room. Several other areas of this factory are not automated, however—notably, assembly and inspection.[23]

The chief problems related to an FMS arise from its complexity and cost. Several years of planning are needed for such a system, and installing and maintaining an FMS is likely to require a higher degree of technical expertise than manufacturers may have available. Finally, because FMS is a system of interdependent tools, reliability problems tend to magnify. In particular, the materials handling portions of FMS are notoriously troublesome. (See below.)

Despite the advantages claimed for FMS, the systems are still relatively rare. Observers estimate that there are 20 to 30 of such systems in Japan, 20 each in Western and Eastern Europe, and 20 to 30 in the United States.[24] The reasons for this scarcity of application include the complexity, newness and cost of the systems. One American manufacturer estimated that FMS cost $600,000 to $800,000 per machining workstation, with a minimum expenditure of $3 million to $4 million.[35] In addition, the inhouse costs of planning for installation of an FMS—a process which often takes several years—are likely to substantially increase the investment in an FMS.

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[21] OTA work environment case study.

[22] M. E. Merchant, "Current Status of, and Potential for, Automation in the Metalworking Manufacturing Industry," *Annals of the CIRP*, vol. 32, no. 2, 1983.

[23] Ibid; D. Nitzan, "Robotics in Japan—A Trip Report," SRI International, February 1982.

[24] "CAM, An International Comparison," *American Machinist*, November, 1981, pp. 207-226; W. Dostal, A. W. Kamp, M. Lahner, and W. P. Seesle, "Flexible Manufacturing Systems and Job Structures" (Mitteilungen aus der arbeitsmarkt and berufsforschung), 1982. Reliable statistics on FMS are difficult to obtain because of conflicting definitions of an FMS and the early stage of the technology's development.

Automated Materials Handling Systems

Automated materials handling (AMH) systems store and move products and materials under computer control. Some AMH systems are used primarily to shuttle items to the work areas or between workstations on automated carts or conveyors. Automated storage and retrieval systems (AS/RS) are another form of automated materials handling, essentially comprising an automated warehouse where parts are stored in racks and retrieved on computerized carts and lift trucks. For the purposes of this report, this category includes only those materials handling systems which are not classified as robots.

How AMH Systems Work.—There are a wide variety of formats for automated materials handling. They include conveyors, monorails, tow lines, motorized carts riding on tracks, and automated carriers which follow wires embedded in the floor of the factory. Each AMH system is unique, and each is designed for the materials handling needs of a particular factory. The common characteristic of these devices is that they are controlled by a central computer.

There are three general applications for AMH. The first is to shuttle workpieces between stations on an FMS. In this case, the AMH system operates on commands from the FMS controller. For example, when the controller receives a message that a machine tool has finished work on a certain workpiece, the controller orders the AMH system to pick up the workpiece and deliver it to the next workstation in its routing. The materials handling portion of the FMS is one of its trickiest elements—part transport needs tend to be logistically complicated, and the AMH system must place the part accurately and reliably for machining. Many AMH systems, such as conveyors or tow chains, are serial in nature—i.e., there is only one path from Point A to Point B. This has caused FMSs to cease operating when a cart becomes stuck or a critical path becomes unusable. FMS designers have responded to this problem by designing AMH systems with backup paths, or by using systems such as the wire-guided vehicle mentioned earlier, which can be routed around disabled carts or other obstacles.

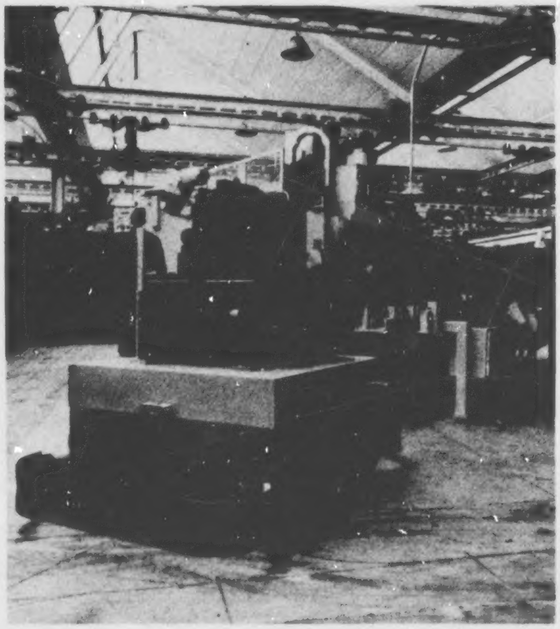

Photo credit: Cincinnati Milacron Corp.

Automated guided vehicle (also known as a "robot cart") follows wires embedded in the floor of the factory in order to shuttle workpieces from one part of the plant to another

The second major application of AMH is for transporting work-in-process from one manufacturing stage to the next within a factory. This application is similar in concept to AMH use for a flexible manufacturing system, although serving an entire factory is more complex. There is more area to cover, more potential obstacles and logistical difficulties in establishing paths for the AMH carriers, and a wider range of materials to handle. For this reason, whole-factory AMH systems are not yet widely used. However, General Motors has recently agreed to purchase automatic guided vehicles from Volvo which allow automobiles to proceed independently through the plant while being assembled. The "robot carts" can be programed to stop at appropriate workstations, and the cart system essentially replaces an assembly line. Volvo uses about 2,000 of the carts in its own plants in Europe.[26] Fiat also uses such carts in Italy.

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[35] P. Johoski, Manager, Manufacturing Systems Division, Cincinnati Milacron Corp., interview, Aug. 16, 1983.

The final application for AMH is in automated storage and retrieval systems. These systems are often very tall in order to conserve space and to limit the number of automatic carrier devices needed to service the facility. In many cases the structure housing the AS/RS is built separately adjacent to the main factory building. Design of an AS/RS depends on the size of the products stored, the volume of material to be stored, and the speed and frequency of items moving in and out of the system. Advocates of AS/RS cite advantages for the system, as compared to nonautomated systems, which include lowered land needs, fewer (but more highly trained) staff, more accurate inventory records, and lower energy use.

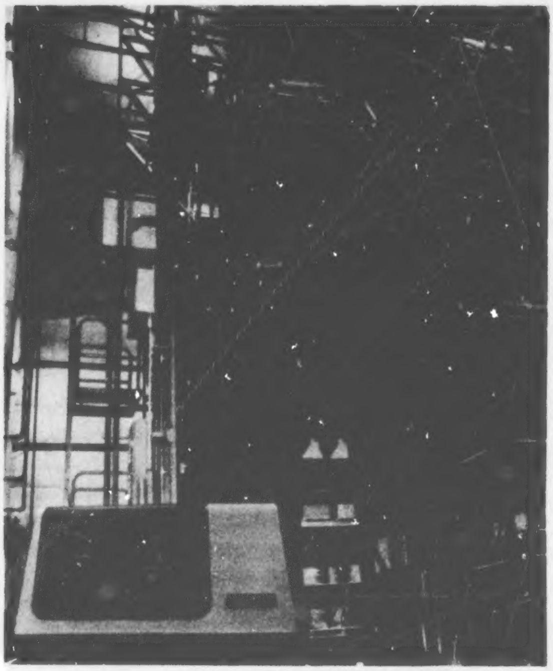

Photo credit: Cincinnati Milacron Corp.

An automated storage and retrieval system (AS/RS), with a computer terminal showing its status. An "automatic stacker crane" (top, center) operates under computer control

Applications.—In theory, AMH systems can move material quickly, efficiently, and reliably, and keep better track of the location and quantities of the parts by use of the computer's memory, thus avoiding much paperwork. They can minimize loss of parts in a factory, which is a common problem in materials handling.

Deere & Co., for example, uses an extensive AS/RS to store materials and inventory at one of its tractor plants.[27] The system's computerized controller keeps track of the products stored on the shelves, and workers can order the system to retrieve parts from the shelves by typing commands at a computer terminal. After they are retrieved from the AS/RS, the parts can be automatically carried by overhead conveyors to the desired location within the plant complex.

IBM's Poughkeepsie plant is planning an AMH conveyor cart system for transporting a 65-pound computer subassembly fixture between assembly and testing stations. The manufacturing manager reports that the decision to adopt this system was prompted by logistical difficulties in keeping track of many such fixtures among a great variety of workstations, as well as by worker health problems related to transporting the fixtures manually.*

AMH systems often have reliability problems in practice. A Deere & Co. executive related an anecdote at a recent National Research Council symposium.[28] Deere's AS/RS was systematically reporting that they had more engines stored on the racks than other records indicated. After long weeks of searching for the problem they finally found the culprit: A leak in the roof was allowing water to drip past the photocell that counted the engines as they were stored. In essence each drip became an engine in the computer's inventory.

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[26] J. Walter, "Volvo Will Build Robot Carts," *The Detroit News*, Sept. 27, 1983.

[27] G. H. Millar, vice president, Engineering, Deere & Co., address to National Research Council seminar on "The Future of Manufacturing in the United States," Washington, D.C., Apr. 13, 1983.

*OTA site visit, IBM Corp., Poughkeepsie, NY, June 9, 1983.

Although Deere's experience is doubtless not widely applicable to AS/RSs, the notion that AMH systems seem to present unexpected logistical and mechanical problems does seem to be generally accurate. Even though these systems are a key aspect of flexible manufacturing systems and of computer-integrated manufacturing, materials handling has long been a neglected topic in industrial research. Materials handling system manufacturers have only recently "caught up" to other industrial systems in level of sophistication, and few companies have so far installed sophisticated AMH systems. Because of this relative lack of sophistication, materials handling for FMS and CIM, especially for a complex application such as delivery of multiple parts to an assembly station, may be one of the biggest problems facing integrated automation.[29]

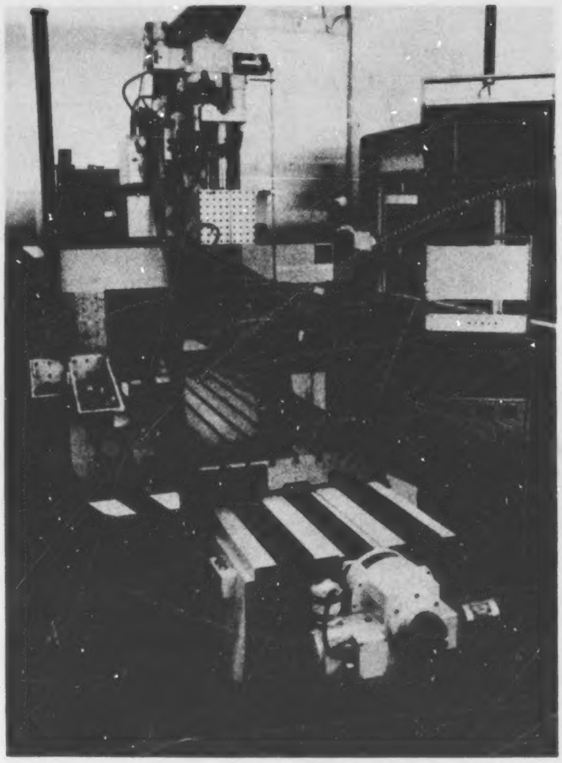

Photo credit: National Bureau of Standards

A Coordinate Measuring Machine uses a tiny but precise probe (center) to automatically measure parts

Other CAM Equipment

While they will not be addressed in detail, there are several other kinds of programmable automation equipment used in manufacturing. They include:

- *Computer-aided inspection and test equipment.*—For mechanical parts, the most prominent such device is the Coordinate Measuring Machine, which is a programmable device capable of automatic and precise measurements of parts. A great variety of inspection and test equipment is also used for electronic parts. IBM's Poughkeepsie plant, mentioned above, performs the vast majority of its testing of microprocessor modules with automatic devices built in-house. In addition, robots can be used as computer-aided inspection and test devices; several two-armed, gantry-style robots are used at IBM to test the wiring for computer circuit boards.* In the test, thousands of pairs of pins on the circuit board must be tested to make sure that they are correctly wired together. Each arm of the robot is equipped with an electronic needle-like probe, and by touching its probes to each pair of pins and passing an electronic signal through the probes, the robot's control computer can determine whether the circuit board's wiring is "OK."

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[28] G. Millar, op. cit.

[29] B. Roth, professor of mechanical engineering, Stanford University, "Principles of Automation," address to the Unilever Symposium on Future Directions in Manufacturing Technology, Apr. 6-7, 1983; and J. Apple, senior vice president, Systecon, Inc., "Retrieval and Distribution Systems—A Pivotal Part of Future Process Planning," address to Technology Transfer Society Symposium on Factory of the Future, Oct. 26-28, 1983.

*OTA site visit, IBM Corp., Poughkeepsie, N.Y., June 9, 1983.

- *Electronics assembly.*—Increasingly, programmable equipment is used to insert components—resistors, capacitors, diodes, etc.—into printed circuit boards. One such system, Dyna-Pert, manufactured by a subsidiary of the Emhart Corp., is capable of inserting 15,000 parts per hour. A programmable machine assembles spools of electronic parts in the right order for insertion into the circuit board, and another machine inserts the components.
- *Process control.*—Programmable controllers (PCs) are being used extensively in both continuous-process and discrete-manufacturing industries. PCs are small, dedicated computers which are used to control a variety of production processes. They are useful when a set of electronic or mechanical devices must be controlled in a particular logical sequence, as in a transfer line where the conveyor belt must be sequenced with other tools, or in heat treatment of metals in which the sequence of steps and temperature must be controlled very precisely. Until the late 1960's, PCs were comprised of mechanical relays, and were "hard-wired"—one had to physically rewire the device to change its function or order of processes. Modern PCs are computerized, and can typically be reprogramed by plugging a portable computer terminal into the PC. A computerized PC is not only more easily reprogramed than a hard-wired device, but is also capable of a wider range of functions. Modern PCs, for example, are often used not only to control production processes but also to collect information about the process. PCs and numerical control devices for machine tools are very similar in concept—essentially, NCs are a specialized form of PC designed for controlling a machine tool.

Programmable Automation and Manufacturing Management

Several kinds of computerized tools are becoming available to assist in management and control of a manufacturing operation. The essential common characteristic of computerized tools for management is their ability to manipulate and coordinate "data bases"—stores of accumulated information about each component of the manufacturing process. The ability to quickly and effectively get access to these data bases is an extraordinarily powerful management tool—what was a chaotic and murky manufacturing process can become much more organized, and its strengths and weaknesses more apparent. The following section describes some of these tools, as well as the notion of "computer-integrated manufacturing," which is not a tool or technology in itself but rather a strategy for organizing and controlling the factory.

Management Information Systems

Manufacturers use and store information on designs, inventory, outstanding orders, capabilities of different machines, personnel, and costs of raw materials, among other things. In even a modestly complex business operation, these data bases become so large and intricate that complex computer programs must be used to sort the data and summarize it efficiently. Management information systems (MIS) perform this function, providing reports on such topics as current status of production, inventory and demand levels, and personnel and financial information.

Before the advent of powerful computers and management information systems, some of the information which MIS now handle was simply not collected. In other cases, the collection and digestion of the information required dozens of clerks. Beyond saving labor, however, MIS bring more flexible and more widespread access to corporate information. For example, with just a few seconds of computer time a firm's sales records can be listed by region for the sales staff, by dollar amount for the sales managers, and by product type for production staff. Perhaps most importantly, the goal for MIS is that the system should be so easy to use that it can be used directly by top-level managers.*

Computer-Aided Planning

Computer-aided planning systems sort the data bases for inventory, orders, and staff, and help factory management schedule the flow of work in the most efficient manner. Manufacturing resources planning (MRP) is perhaps the best-known example of computer-aided planning tools.** MRP can be used not only to tie together and summarize the various data bases in the factory, but also to juggle orders, inventory, and work schedules, and to optimize decisions in running the factory. In some cases these systems include simulations of the factory floor so as to predict the effect of different scheduling decisions. MRP systems have applicability for many types of industry in addition to metalworking.

Another kind of computer-aided planning tool is computer-aided process planning (CAPP), used by production planners to establish the optimal sequence of production operations for a product. There are two primary types of CAPP systems—variant and generative.

The **variant** type, which represents the vast majority of such systems currently in use, relies heavily on group technology (GT). In GT, a manufacturer classifies parts produced according to various characteristics: e.g., shape, size, material, presence of teeth or holes, and tolerances. In the most elaborate GT systems, each part may have a 30- to 40-digit code. GT makes it easier to systematically exploit similarities in the nature of parts produced and in machining processes to produce them. The theory is that similar parts are manufactured in similar ways. So, for example, a process planner might define a part, using GT classification techniques, as circular with interior holes, 6'' diameter, 0.01'' tolerance, and so forth. Then, using a group technology-based CAPP system, the planner could recall from computer memory the process plan for a part with a similar GT classification, and edit that plan for the new, but similar, part.

Generative process planning systems, on the other hand, attempt to generate an ideal routing for a part based on information about the part and sophisticated rules about how such parts should be handled, and the capabilities of machines in the plant. The advantage of such systems is that process plans in variant systems may not be optimal. A variant system uses as its foundations the best guesses of an engineer about how to produce certain parts. The variants on that process plan may simply be variations on one engineer's bad judgment.

Though generative CAPP may also depend on group technology principles, it approaches process planning more systematically. The principle behind such systems is that the accumulated expertise of the firm's best process planners is painstakingly recorded and stored in the computer's memory. Lockheed-Georgia, for example, developed a generative CAPP system called Genplan to create process plans for aircraft parts (see photo for an example of a process plan developed by Genplan). Engineers assign each part a code based on its geometry, physical properties, aircraft model, and other related information. Planners can then use Genplan to develop the routing for the part, the estimated production times, and the necessary tooling. Lockheed-Georgia officials report that one planner can now do work that previously required four to eight people, and that a planner can be trained in 1 year instead of 3 to 4.*

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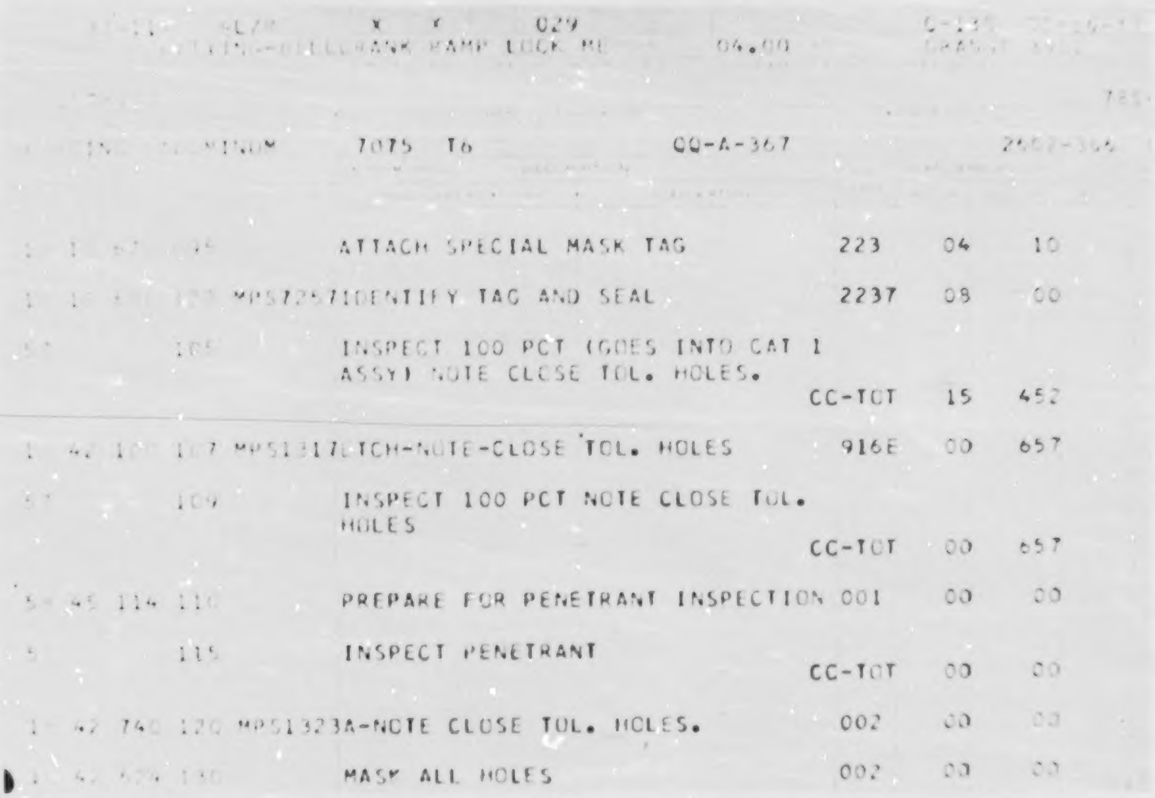
*Sometimes the terms "management information system" and "data base management system" (DBMS) are used interchangeably. MIS tends to refer to a more powerful and comprehensive DBMS aimed for use by relatively high-level staff.

**Two forms of MRP are mentioned in industry literature. The earlier version was materials requirements planning, a more limited form of computer-aided planning system for ordering and managing inventory. Manufacturing resources planning is sometimes known as MRP II to distinguish it from this earlier notion.

*OTA site visit, Lockheed-Georgia, Mar. 10-11, 1983. Genplan was derived from a generative CAPP system developed by Computer Aided Manufacturing-International—a consortium for programmable automation research (see ch. 8).



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 1 42 740 120 MPS1323A-NOTE CLOSE TOL. HOLES.          002    00    00

                 MASK ALL HOLES                        002    00    00
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Photo credit: Lockheed-Georgia Corp.

An excerpt from a process plan developed by the "Genplan" system

Computer-Integrated Manufacturing

Computer-integrated manufacturing (CIM, pronounced "sim") involves the integration and coordination of design, manufacturing, and management using computer-based systems. Computer-integrated manufacturing is not yet a specific technology that can be purchased, but rather an approach to factory organization and management.

Computer-integrated manufacturing was first popularized by Joseph Harrington's book of the same name, published in 1974. One systems expert recounts the history of the concept in this way:

> [CIM] came about from: 1) The realization that in many cases automation for discrete activities in manufacturing, such as design or machining, in fact often decreased the effectiveness of the entire operation—e.g., designers could conceive parts with CAD that could not be made in the factory; NC machine tools required such elaborate setup that they could not be economically programmed or used. 2) Development of large mainframe computers supported by data base management systems (DBMS) and communications capabilities with other computers. The DBMS and communications allowed functional areas to share information with one another on demand. 3) The dawning of the microcomputer age which began to allow machines in the factory to be remotely programmed, to talk to each other and to report their activity to their ultimate source of instruction.[30]

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[30] D. Wisnosky, group vice president, GCA Corp., Industrial Systems Group, personal communication, October 1983. Wisnosky is a former director of the U.S. Air Force Integrated Computer-Aided Manufacturing Program (ICAM).

Though there is no quantitative measure of integration in a factory, and definitions of CIM vary widely, the concept has become a lightning rod for technologists and industrialists seeking to increase productivity and exploit the computer in manufacturing. For example, James Lardner, vice president of Deere & Co., sees the current state-of-the-art manufacturing process as a series of "islands of automation," in which machines perform tasks essentially automatically, connected by "human bridges." The ultimate step, he argues, is to connect those islands into an integrated whole through CIM and artificial intelligence (described in the next section of this chapter), replacing the human bridges with machines. In this essentially "unmanned factory," humans would then perform only the tasks that require creativity, primarily those of conceptual design. Lardner's vision is echoed by many other prominent experts.

Experts differ in their assessment of how long it might take to achieve this vision—virtually no one believes that it is attainable in less than 10 to 15 years, while some experts would say an unmanned factory is at least three decades away. More importantly, there are other technologists who argue that the vision may, in fact, be just a dream. For example, Bernard Roth, professor of mechanical engineering at Stanford University, argues that factories will, in reality, reach an appropriate and economical level of automation and then the trend toward automation will level off. In a sense, the difference between these two views may be a difference of degree rather than kind. For many factories, the "appropriate" level of automation might indeed be very high. In others, however, a fair number of humans will remain, though they may be significantly fewer than is currently the case.

Integrated systems are often found to require more human input than was expected.[31] Indeed, as one engineer explains:[32]

> There is much talk about the totally automated factory—the factory of the future—and night shifts where robots operate the factory. Whereas these situations will develop in some cases . . . many manufacturing facilities will not be fully automated. Even those that are will involve humans in system design, control, and maintenance—and the factory will operate within a corporate organization of managers and planners.

These two views do have important significance for how an industrialist might now proceed. Many who hold the vision of the unmanned factory seem to emphasize technologies, such as robotics, that can remove humans from manufacturing. Those who do not share the vision of "unmanned manufacturing" tend to argue that there are more practical ways to enhance productivity in manufacturing, including redesigning products for ease of fabrication and assembly.

How CIM Works.—There are two different schemes for CIM: In **vertically** integrated manufacturing, a designer would design a product using a CAD system, which would then translate the design into instructions for production on CAM equipment. Management information systems and computer-aided planning systems would be used to control and monitor the process. A **horizontal** approach to integration, on the other hand, would attempt to coordinate only the manufacturing portion of the process; i.e., a set of computer-aided manufacturing equipment on the factory floor is tied together and coordinated by computer instructions. A flexible manufacturing system would be a good example of such horizontal integration.* Vertically integrated manufacturing is what is most commonly meant by CIM, however, and many experts would consider horizontal or "shop floor" integration to be only partial CIM. Figure 9 is a conceptual framework for CIM which illustrates the role of some of the PA technologies at various levels of factory control.

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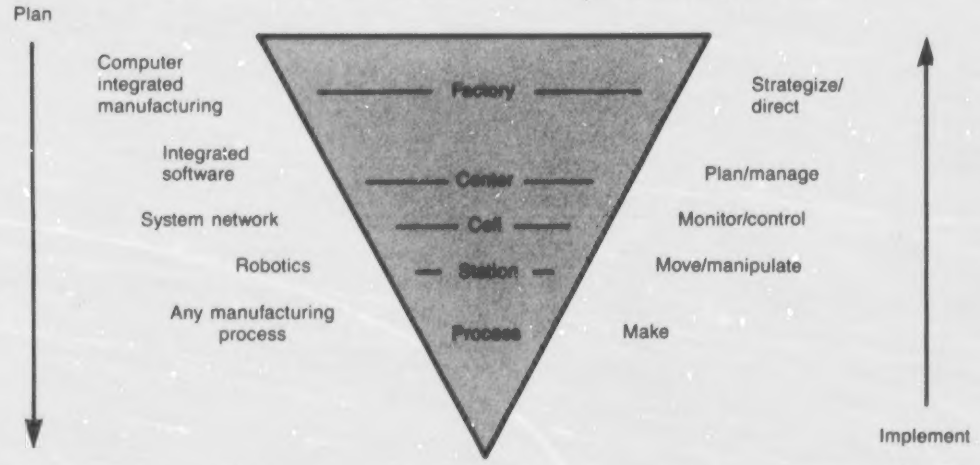
[31] This phenomenon has been noted in a variety of places, including OTA work environment case studies, and the OTA Automation Technology Workshop, May 29, 1983.

[32] B. Burns, Manufacturing Technology Group Engineer, Lockheed-Georgia Co., cited in "Considering People Before Implementation," *CAD/CAM Technology*, fall 1983, p. 6.

*Vertical and horizontal integration of programmable automation equipment should not be confused with vertical and horizontal integration in the markets for selling this equipment; this will be discussed in chapter 7.

Figure 9.—Programmable Automation Factory Hierarchy (Simplified)



SOURCE: GCA Corp., Industrial Systems Group

A vertically integrated factory usually implies maximum use and coordination of all PA technologies, and can involve much more centralized control of manufacturing processes than a nonintegrated production process. Communication and shared data bases are especially important for CIM. For example, CAD systems must be able to access data from inventory on the cost of raw materials, and from CAM systems on how to adapt the design to facilitate manufacture. Computer-aided manufacturing systems must be able to interpret the CAD design and establish efficient process plans. And management computer tools should be able to derive up-to-date summary and performance information from both CAD and CAM data bases, and effectively help manage the manufacturing operation.

Some parts of the above requirements are already possible, while others seem far on the horizon. Factory data bases now tend to be completely separate, with very different structures to serve different needs. In particular, the extensive communications between CAD and CAM data bases will require more sophistication in both CAD and CAM, research on how to establish such communications, and finally, major changes in traditional factory data structures in order to implement such a system.

Applications.—CIM sounds like utopia to many manufacturers because it promises to solve nearly all of the problems in manufacturing that were identified in the section on "the manufacturing process" at the beginning of this chapter, and in particular it promises to dramatically increase managerial control over the factory. Design changes are easy with extensive use of CAD; CAP and MIS systems help in scheduling; FMS and other CAM equipment cut turnaround time for manufacture, minimize production costs, and greatly increase equipment utilization; connections from CAD to CAM help create designs that are economical to manufacture; control and communication is excellent, with minimal paper flow; and CAM equipment minimizes time loss due to setup and materials handling.

Many of the companies which make extensive use of computers view their factories as examples of CIM, but on close examination their integration is horizontal—in the manufacturing area only—or at best includes primarily manufacturing and management. Boeing, however, has made substantial strides toward a common design and manufacturing data base system in their CAD/CAM Integrated Information Network (CIIN). Similarly, General Electric, as part of its effort to become a major vendor of factory automation systems, has embarked on ambitious plans for integration at several of its factories, including its Erie Locomotive Plant, its Schenectady Steam Turbine Plant, and its Charlottesville Controls Manufacturing Division.

Technical Trends and Barriers: Future Applications

While the possibilities for application of existing programmable automation tools are extensive, the technologies continue to develop rapidly. They depend on and share the extraordinary rate of growth in technical capabilities of computer technologies as a whole.

There are five themes in the directions for development in each of the technologies. They are:

- increasing the **power** of the technologies—i.e., their speed, accuracy, reliability, and efficiency;
- increasing their **versatility**—the range of problems to which the technologies can be applied;
- increasing the **ease of use**, so that they require less operator time and training, can perform more complex operations, and can be adapted to new applications more quickly;
- increasing what is commonly called the **intelligence** of the systems, so that they can offer advice to the operator and respond to complex situations in the manufacturing environment; and
- increasing the **ease of integration** of PA devices so that they can be comprehensively coordinated and their data bases intimately linked.

This section first summarizes the principal research efforts and directions for development of the five technologies on which this report primarily focuses: CAD, robotics, NC machine tools, FMS, and CIM. Next, it summarizes issues in several technical areas which have a large potential impact on all the technologies: artificial intelligence, standards and interfaces, human factors, materials, and sensors. Chapters 8 and 9 describe the institutional context for research and development (e.g., sources of R&D funding), and compare R&D programs on an international basis.

Trends and Barriers in Five Technologies

Computer-Aided Design

There are at least three generations of CAD equipment, two of which are widely available commercially, with the third still largely in prototype applications and R&D labs. The first are the 2-D computerized drafting systems mentioned earlier in the chapter, which streamline the process of drawing and, especially, editing the drawings of parts, plans, or blueprints. The second generation are 3-D CAD systems, which allow the user to draw an image of a part using either wireframe models or "surfacing" (displaying the surfaces of objects).

The third generation, commercially available within the past few years but still in their infancy, are the so-called solid modelers. Such systems (actually an expanded 3-D capability) can be used not only to draw the object in three dimensions but also to obtain a realistic visualization of the part. Users can rotate, move and view the part from any angle, and, in some cases, derive performance characteristics. Engineers at IBM's Poughkeepsie plant, for example, use an advanced CAD system of this type to design cabinet arrangements for IBM mainframe computers. Because the system "constructs" a sophisticated solid model of an object, it can be used to visualize such design issues as component clearance problems. One can even "pull out a drawer" to make sure it does not hit a cable, for instance.

Photo credit: Computervision Corp.

An exploded view of a part assembly from a CAD system with solid modeling capabilities

There seems to be a consensus among manufacturing managers and researchers that such third-generation 3-D CAD systems are a critical element in the progress toward effective and powerful use of programmable automation in factories. The increased sophistication of 3-D systems greatly improves the ability of such systems to communicate design specifications to manufacturing equipment. While third generation 3-D systems are technically feasible now, there are nontechnical barriers to implementation of 3-D systems, in part because of the complexity of the systems and the problems encountered in switching from 2-D to 3-D systems.[33] In fact, there is a need for a fourth generation, a CAD system which offers more "intelligent" design assistance and can be easily linked to other programmable automation systems for manufacturing and management.

Indeed, there seem to be three related themes in current CAD research:

1. improving the algorithms for representing objects using the computer so designers can create and manipulate complex objects in an efficient and intuitively clear fashion;
2. adding "intelligence" to CAD systems so that they prevent design errors and facilitate the design process; and
3. developing effective interfaces between CAD systems and manufacturing and management.

Improving Algorithms.—Representing shapes in computer memory and manipulating those representations has been and remains a difficult challenge for computer researchers. As the power and complexity of CAD systems increase, their computing needs grow rapidly. One of the problems in manipulating complex shapes with the computer is illustrated by the experimental CAD system used for computer cabinet design at IBM: One of its creators reported that a typical manipulation of a complex object—say, generating an image of the cabinet from a different viewing angle, with all hidden lines removed—might take several minutes of computer processing time.* Although the system is still useful, clearly quicker response is needed for the designer to have optimal flexibility from a CAD system. A shorter response time can come from a faster computer or from more efficient ways of representing and manipulating shapes in computer memory.

Although faster computers are unquestionably on the horizon, much of the current research on CAD involves attempts at more efficient representations. The efficiency of a certain scheme also depends on how easy it is to use. A wide variety of schemes are being studied, none of which has a clear overall superiority. One scheme, called "constructive solid geometry," involves assembling images by combining simple shapes, such as blocks, cylinders, and spheres. The other is boundary representation, in which an object is constructed as a set of individual surfaces. For example, one system being developed by a group at the University of Utah is based on "splines." The designer manipulates on the screen the equivalent of the thin metal strips used in models of boats or planes. He or she can expand them, curve them, cut them, and so forth to create the model.[34]

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[33] R. Simon, Computervision Corp., personal communication, Oct. 6, 1983.

*OTA site visit, D. Grossman, IBM Corp. Yorktown Heights, N.Y., June 8, 1983. "Hidden lines" in images are those edges of a solid object that one cannot see from a given viewing angle. Grossman reports that when CAD is used for such mechanical models as the computer cabinets discussed here, each model consists of a polyhedron with roughly 40,000 separate faces for the computer to store, manipulate, and determine whether they would be "hidden" or not.

There is some concern that not enough time and effort in industry is being devoted to expanding the technologies, particularly the algorithms available for "solids modeling," i.e., for true three-dimensional representations of objects. Thus the "experience base" of industries experimenting with 3-D systems is very small, and such experience is necessary to refine the systems and determine the needs of manufacturing industries.

Adding "Intelligence" to CAD.—In the industry there is much discussion of "smart" CAD systems which would not permit certain operator errors. For example, they would not permit the design of an object that could not be manufactured, a case without a handle, or a faulty circuit board. Further, they would facilitate the designer's work by such functions as comparing a design to existing designs for similar objects, and storing data on standard dimensions and design sub-units, such as fastener sizes and standard shapes. Such systems might also increase the ability of CAD systems to simulate the performance of products. There is much concern over "bad design" in industry, and intelligent CAD systems are considered one way to improve the situation.

Though such systems have become rather advanced in electronics applications and offer some hope of becoming more so, there is as yet little in the way of "smart" CAD systems for mechanical applications. A few systems can be programed to question a designer's choice of certain features that are nonstandard—a 22-mm screw hole in a shop that only uses 20- and 30-mm holes, for instance. Some researchers feel that it will be possible to use an "expert" system (see the next section's discussion of artificial intelligence) for developing a "smart" CAD system.

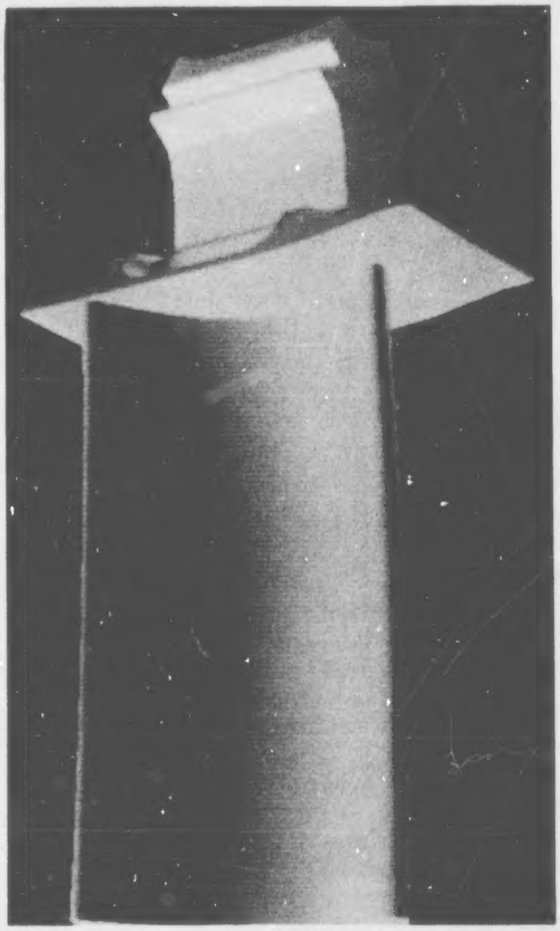

Photo credit: University of Utah

A CAD image of a part from a system based on "splines"

CAD as Part of Computer-Integrated Manufacturing.—Perhaps the most important research theme involves connecting computer-aided design to other computerized systems in the factory. Such connections would mean, for example, that design information could be forwarded directly to machine tools that make the part, that designers could draw on previous designs as well as data on their performance and cost, and that designers would have up-to-date information on the manufacturability and cost of their designs. Such comprehensive connections between design and manufacturing are currently far beyond the state-of-the-art.

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[34] R. Reisenfeld, professor of computer science, University of Utah, personal communication.

There has, however, been modest progress toward interfaces between CAD devices. The Initial Graphics Exchange Standard, developed at the National Bureau of Standards under U.S. Air Force sponsorship, allows different CAD systems to exchange data (see ch. 8). However, while interfaces between computer-aided design systems are becoming easier, there is as yet little progress in allowing CAD and CAM systems to communicate. In some cases these devices can be wired together into a computer network, but establishing an effective interface requires sophisticated software to manipulate manufacturing information so that it is useful for designers, and vice versa.

Movement toward design-manufacturing connections is impeded by a strong tradition of separatism among design engineers and manufacturing engineers. A common description of the relationship is, "The design engineer throws the set of drawings over the wall to manufacturing." There is evidence that such barriers are beginning to break down, slowly, as the need for communication has become apparent, and as engineering schools have begun to broaden the connections between design and manufacturing curricula.

There are many research efforts whose ultimate goal includes such connections between CAD and other manufacturing systems. These research programs include the Air Force's Integrated Computer Aided Manufacturing project, as well as the National Bureau of Standards (NBS) National Engineering Laboratory and a joint West German/Norwegian effort (see ch. 9). The heart of the latter effort is an attempt to use a very advanced geometric modeling system developed by the Technical University of Berlin as the basis for developing software which would allow design to be connected to all aspects of the manufacturing process. In addition, users of PA, such as GE and IBM, are also working on interface issues. However, full integration still seems at least a decade off.

Robotics

Robotics research is currently an area of intense interest in both industry and universities. There are a dozen or more universities with significant ongoing research projects in robotics, and perhaps 3 dozen industrial firms and independent laboratories. Government labs at NBS, the National Aeronautics and Space Administration (NASA), and several at DOD, are also involved.

In part because of the technical immaturity of robotics technology, and in part because it is a complex and interdisciplinary technology, there are many discrete areas of research problems and possible directions for extension of capabilities. The problem areas include:[35]

- *Improved positioning accuracy for the robot's arm.*—Increased accuracy is essential for many applications of robots, particularly in assembly operations and other cases where a robot is programed offline. While current robots are precise (they can return to the same position on each cycle fairly reliably, within perhaps 0.005 inch), their accuracy (the ability to arrive at a predetermined point in space), is not nearly so reliable. Several techniques are being used to increase accuracy in robots. Though the traditional answer has been to increase the stiffness and mechanical precision of the manipulator arm, such approaches can greatly increase the weight and cost of the unit. Software calibration, a technique being developed at the NBS, involves adjusting the robot's electronics to compensate for inaccuracies in its movements. Another technique involves using machine vision systems to "watch" the robot in action and correct its movements as they occur—this technique could potentially improve both accuracy and precision. Of the two, software calibration is far simpler technically and is likely to be available far sooner.

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[35] J. S. Albus, "Industrial Robot Technology and Productivity Improvement," *Exploratory Workshop on the Social Impacts of Robotics: Summary and Issues* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-BP-CIT-11, February 1982), pp. 62-89.

- *Increased "grace, dexterity, and speed."* —The physical structure of the manipulator—its material, actuation mechanism, and joints—has remained substantially the same for several decades. Several groups of researchers, sponsored by NASA and the Defense Advanced Research Projects Agency (DARPA), among others, are working on lighter structures for the robot arm. These would most likely consist of composite fiber materials similar to those now used extensively on aircraft—about one-sixth the weight of steel. Though the technology for such structures exists, composites are extremely expensive and the cost is holding back further use in robotics. Other directions for progress in robot structures include fundamentally different designs for the manipulator arm. A Swedish group has developed an arm which is structured in some ways like a human spinal column, while other research is directed toward using "tendons" to effect movement of the arm, as in the human musculoskeletal interaction.

  Cost is not the only drawback to the use of lighter structural materials. In addition, the robot's controller must become more sophisticated in order to direct the motions of a lightweight, and inherently somewhat flexible, robot arm. For instance, computer scientists and mathematicians must develop control algorithms that will prevent backlash—i.e., the "play" or vibration that occurs when the arm is moved quickly from one position to another.

  Finally, gripper design needs to be made more flexible. Directions for progress in grippers include both developing "hands" that can be used to manipulate a wider variety of objects, and also developing "quick-change" grippers so that the robot can autonomously exchange one "hand" for another.
- *Sensors, including vision, touch and force.* —Because sensors can be applied to a wide range of programmable automation devices, they will be addressed in a separate section later. One problem relevant to robots is the development of control systems that can accommodate sensory information. Systems are only now beginning to become available that can accept feedback from various kinds of sensors. In part, these systems have developed in conjunction with new generations of robot programing languages, to be discussed below. A continuing tension in development of robots is whether one should structure the robot's environment so that it does not need extensive sensing, or try to provide sensors to enable it to cope with an unstructured environment.
- *Model-based control systems.*—The most advanced and versatile controller for a robot would be one that had an internal model of its environment. In other words, it would have a store of information about the three-dimensional world, what the objects it worked with were supposed to look or feel like, and the rules for how physical objects interact with each other. Although this problem has intrigued many technologists, who view it as one of the ultimate solutions for expanding robot versatility and "intelligence," it is extraordinarily difficult to impart such information to the machine, and even to decide how one might structure such information.
- *Software.*—Methods for programing robots are becoming easier and more efficient, although there is still substantial work needed in this area. Two languages have been released recently—IBM's A Manufacturing Language (AML) and RAIL, by Automatix—which are considerably more powerful than traditional robot languages, and which permit more sophisticated programing techniques, similar to advanced general-purpose computer languages such as PASCAL or ADA. Most other programing languages currently available are rather cumbersome and inflexible by computer-industry standards. At the same time, teaching-by-guiding programing is becoming less practical for complex applications; it

delays production and has very limited capabilities for editing the program or using sensory information.

There is still much progress to be made in human interfaces with robots—the design of languages and programing systems that can be most easily and effectively used by humans. One technique for improving human interfaces, which has just become available, is the use of CAD to program robots and simulate their operation. The ability to visualize the robot's path may permit more effective planning and and debugging of programs so that production need not be stopped in order to test a robot program.

- *Interface standards.*—Standards need to be developed for communication of information between robots and machine tools, sensors, and control computers. While such standards are a tractable problem, programmable automation producers, as well as the computing industry, are only beginning to make progress in establishing standards, and the standards-making process is long and intricate. In the meantime, efforts to establish interfaces between robots and other automated devices are hindered by a lack of standards. Researchers at NBS report that some manufacturers refuse to divulge details of the operation of their equipment that

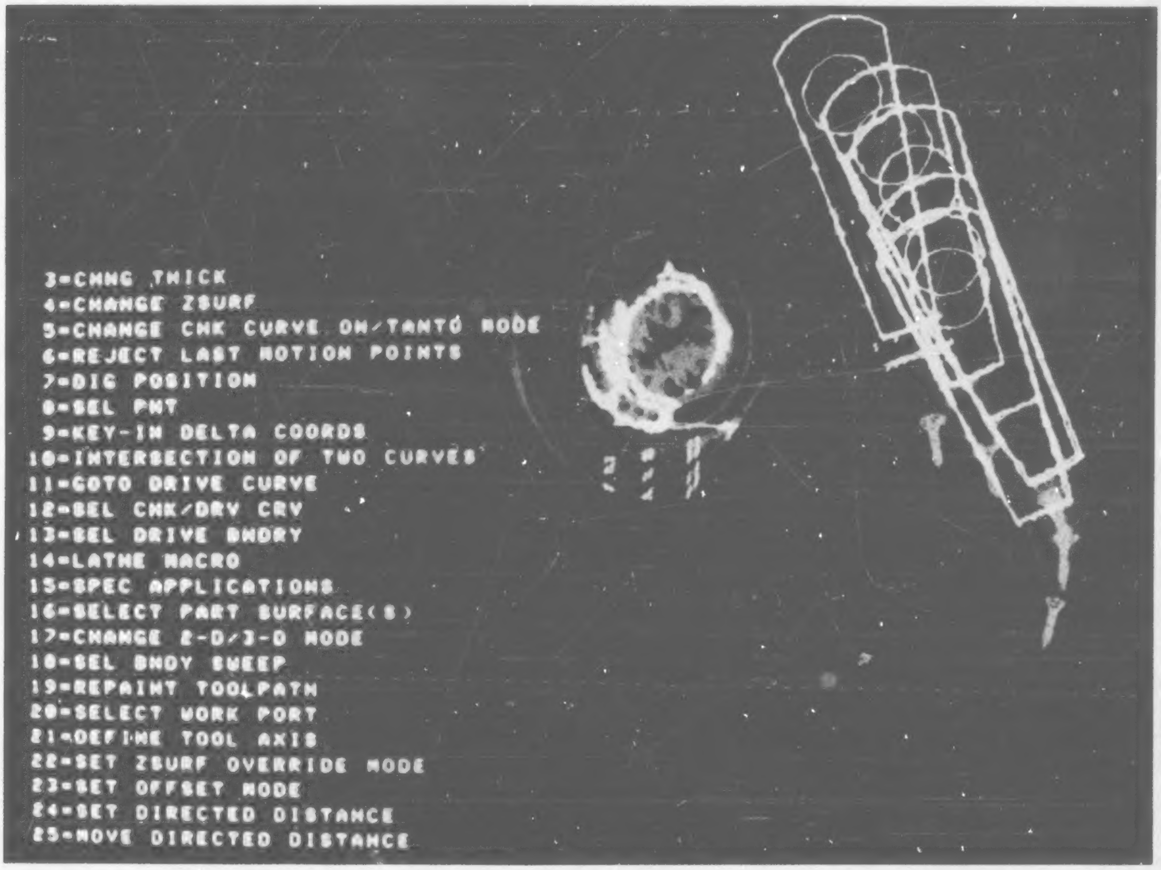
3=CHNG THICK
4=CHANGE ZSURF
5=CHANGE CHK CURVE ON/TANTO MODE
6=REJECT LAST MOTION POINTS
7=DIG POSITION
8=SEL PNT
9=KEY-IN DELTA COORDS
10=INTERSECTION OF TWO CURVES
11=GOTO DRIVE CURVE
12=SEL CHK/DRV CRV
13=SEL DRIVE BNDRY
14=LATHE MACRO
15=SPEC APPLICATIONS
16=SELECT PART SURFACE(S)
17=CHANGE 2-D/3-D MODE
18=SEL BNDY SWEEP
19=REPAINT TOOLPATH
20=SELECT WORK PORT
21=DEFINE TOOL AXIS
22=SET ZSURF OVERRIDE MODE
23=SET OFFSET MODE
24=SET DIRECTED DISTANCE
25=MOVE DIRECTED DISTANCE

Photo credit: Computervision Corp.

A CAD-based simulation of a robot's operation would enable the equipment to be linked to other computers. (See the following discussion of standards and interfaces.)

- *Mobility.*—While techniques for limited movement along rails are already available for robots, the more general problem of developing a robot that could navigate its way through a cluttered factory is far more difficult. There is some argument about whether such mobility is even necessary for the factory—some would assert that such technology is too esoteric for the factory, and the plant should instead be organized so that mobility is unnecessary. There is substantial research in mobility, however, in large part sponsored by DOD agencies for specific battlefield applications.

Numerically Controlled Machine Tools

Although machine tools are a well-established technology, there continues to be a need for substantial improvements in the tools and their controllers. A "Machine Tool Task Force," operating under the auspices of DOD's Air Force Materials Laboratory, issued a report in 1980 calling for hundreds of improvements and new research efforts. Among the ones most relevant to this study are those listed in table 10.[36]

The bulk of machine tool R&D takes place in the laboratories of machine tool and controller manufacturers. A smaller but significant amount of work is undertaken at university mechanical engineering departments, with funding from industry or the Federal Government. The chief research problems can be divided into those involving the machine itself, and those involving the controller.

The Machine Tool.—Many of the development needs for machine tools involve devices which facilitate the use of the tools under computerized control. For example, chip removal —disposal of the metal shavings that accumulate in large volume during machining—is a big problem in industry, a problem that gets bigger as machines get more efficient and more automated. Various schemes have been used for chip control and disposal, none of which are entirely satisfactory. Many engineers believe the answer is not to create the chips in the first place—by forging the part close to its final shape, for example, or machining with lasers instead of cutting tools. While "near net shape" forging is becoming more prevalent, laser machining is still immature, and not yet practical for widespread applications.

Another problem in machine tools, whether automated or manual, is tool wear. A drill bit or grinding wheel has a fixed useful life, after which the quality of cut begins to decline and the tool eventually fails. The traditional solution to tool wear is simply for an experienced

Table 10.—Machine Tool Task Force Recommendations for Improving Machine Tool Controls

Area of improvement	Hardware (H) or software (S) development	Objective
Toolsetting	H/S	Reduce setup time, improve accuracy
Diagnostics and sensors	H/S	Allow more of the important parameters to be sensed and monitored for failure identification
Fixturing/clamping	H	More versatility of fixture and less setup time
NC programing and instruction	S	Develop improved new computer subroutines to simplify and reduce time for programing
Programmable controls	H	Integrate machine processes into computerized system; enhance conventional machine operations; provide interfacing devices and flexibility
Interface standards	H/S	Improve upgrading and growth-retrofit potential; interchangeability

SOURCE: Machine Tool Task Force, *Technology of Machine Tools*, October 1980.

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[36] Machine Tool Task Force, "Technology of Machine Tools: A Survey of the State of the Art" (Livermore, Calif.: Lawrence Livermore National Laboratory, October 1980)

machinist to listen to the machine tool and, ideally, sense when noise and vibrations become abnormal. In situations where that is not possible, particularly on CNC machine tools, machinists replace the tool after a specified period of tool life. In addition, the Japanese are said to run their machines at slower speeds in order to minimize tool failure during unmanned machining. However, tools can fail at almost any point in their use—a drill bit may fail after it only drills a few holes, or it may last for hours. This variability makes prescheduled replacement difficult and inefficient. There has been some progress in developing devices that can sense tool wear and report when tool change is needed. The National Bureau of Standards, for example, has a prototype device that "listens" to the vibrations produced by the tool and can be "taught" to recognize abnormal vibrations.

The rate at which a machine tool can cut metal depends on many factors—the type of metal, the depth of cut, the condition of the tool, and so forth. Controlling the speed of cut or the feed rate so as to cut metal at optimum removal rates has been a continuing research and development problem in the industry. As with sensing tool wear, the traditional answer has been for experienced machinists to adjust a cutting speed or feed rate dial on the machine. In the past decade, various "adaptive control" devices have been developed which vary the "speeds and feeds" of the machine tool based on motor load, for instance. However, these devices have had uneven reputations for effectiveness and reliability.

Finally, a great deal of effort is now being devoted to increasing precision in machine tools. The Navy's precision manufacturing program will be described in chapter 8.

Related to improvements in precision, a long-term goal for machine tool technology involves measurement of parts during machining. With such a scheme, quality problems could be identified and corrected during manufacturing rather than afterwards, thereby reducing waste. NBS has done some preliminary research on such a system of on line metrology at machine tools, although commercial use of such systems is limited to very simple and predictable part geometries.

Machine Tool Controllers.—As with all other forms of programmable automation, there is continuing demand for and research on simplifying programing of NC machine tools; the same holds true for the need to simplify and set standards for interfaces—between machine tool and controller, between machine tools, and between machine tools and other automation devices. A critical issue is the development of effective interfaces between CNC machines and other computerized devices, so that, for example, CNC machines can derive their cutting instructions from the stored dimensions of a design produced with CAD. This is now possible only in specific limited situations, where tremendous effort has been devoted to developing the interfaces for a particular application.

Flexible Manufacturing Systems

Flexible manufacturing systems for the machining of prismatic parts are becoming more prevalent, and are a relatively established technology. FMS for rotational parts are just beginning to be available, while the range of other possible applications for FMS—grinding, sheet metal working, or assembly—are not beyond the reach of current technology, but are only at early stages of development.

Many of the chief R&D problems for FMS involve logistics: design and layout for the FMS, and computer control strategies that can handle sophisticated combinations of powerful machine tools. In addition, there is a need for more sophistication in simulation systems for the FMS so that their efficiency can be optimized.

There are a variety of enhancements to FMS hardware which seem to be on the horizon. In addition to all of the developments described under the individual technologies, these include automatic delivery and changing of cutting tools, and systems for automatic fixturing and defixturing of material to be processed.

Improving the reliability and versatility of materials handling systems is also an important need for FMS. As mentioned earlier, the level of sophistication in materials handling technology often does not match that of other PA technologies, and the AMH system may be the "weak link" in the FMS.

Computer-Integrated Manufacturing

Computer-integrated manufacturing receives substantial attention in industry discussions and trade journals, though there is relatively little active R&D at this level of the computerized factory. This is at least partly because there is not yet substantial demand for CIM systems. GE and IBM have begun to work on computer-integrated manufacturing, as have some Japanese firms, particularly Hitachi, and a coalition of laboratories in West Germany and Norway. The Automated Manufacturing Research Facility at NBS is perhaps the largest test bed for CIM techniques. It is described in more detail in chapter 8.

As with FMS, one of the key issues in CIM development involves the logistics of a complicated factory. Several groups, including NBS, the U.S. Air Force ICAM project, and Computer-Aided Manufacturing International (CAM-I), have been working on "architectures" for such an automated factory. Figure 10 is an example of such a conceptual framework for CIM which forms the foundation for detailed work on factory control architectures.

One of NBS's major contributions in automation R&D has been in developing strategies for the interface of programmable automation devices. Their emphasis has been on what they call a "mailbox" or decentralized approach to factory communication and control. In such a system, the control of the factory is distributed at different levels among the various PA devices (see fig. 10). For example, a factory-level computer might send a message to a production-level computer—"Make 150 of part number 302570." The production-level computer would then send a message to the "mailbox" of a certain work cell—"Execute production plan for part 302570, 150 times." In turn, the work cell controller would send messages to the mailbox of the machine tools and robots in the cell, to execute certain programs stored in their memory.

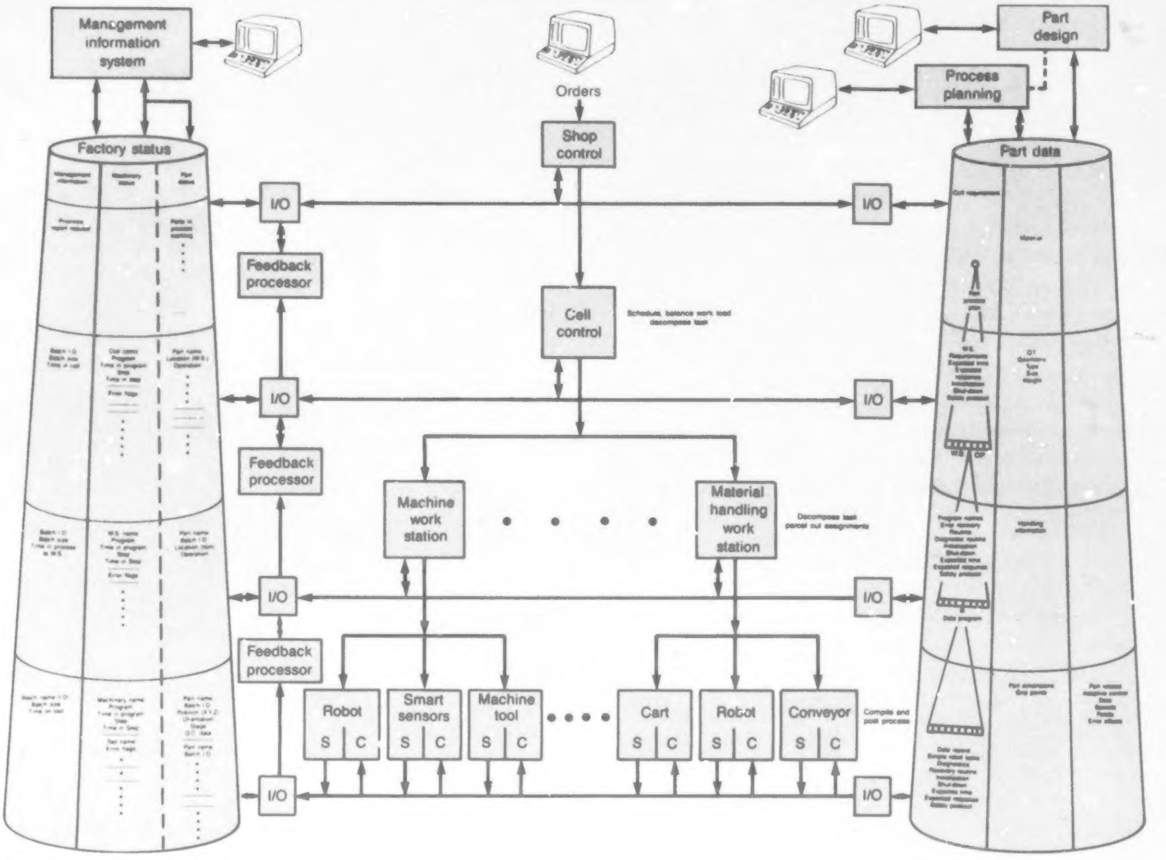
The "mailbox" approach differs from a centralized, or "star," approach to automated systems control in which a central computer directly controls each action of every machine in the factory. The advantages of the mailbox system are that it simplifies standards and interface problems—the only interface standard necessary is for the location of the mailbox in which to deposit messages. This allows one robot to be substituted for another, for example, with relative ease. The mailbox approach allows different PA devices to operate using different languages and proprietary operating systems, as long as they are able to interpret messages from the computer controller.

Hierarchical arrangements for automated manufacturing, such as those illustrated in figure 10, tend to involve a large number of separate computers, each with separate data bases. Techniques for "distributed data base management," that is, managing and manipulating data in several computer systems simultaneously, need to be developed in order for a hierarchical arrangement to be practical. Similarly, techniques and standards for establishing communication between computerized devices, both in-plant and between plants, need to become much more sophisticated.

A group of researchers at Purdue University, in collaboration with several large manufacturers, is attempting to exploit currently available technology to design an actual factory with maximum computer integration. The leader of that effort argues that the technology for CIM is available, and that technical advances, though welcome, are not necessary. Rather, he argues that factors holding back "fully" automated manufacturing are primarily:

1. the lack of standards for interfaces, communication networks, and programing languages;
2. a need for more powerful data-base management systems;
3. the need for detailed mathematical

Figure 10.—NBS Scheme for Distributed Factory Control


Management information system
Orders
Part design
Process planning
Shop control
Factory status
Part data
I/O
Feedback processor
Cell control
Schedule, balance work load decompose task
Machine work station
Material handling work station
Decompose task parcel out assignments
Robot
Smart sensors
Machine tool
Cart
Robot
Conveyor
Compute and post process
S
C

SOURCE: National Bureau of Standards

models of physical and chemical processes;

4. shortages of technical personnel;
5. shortages of computer power; and
6. manufacturing management who are unaware of the detailed technical benefits of automation.[37]

Technical Trends and Barriers: Cross-Cutting Issues

The following issues are not primarily connected to a particular automation technology, but rather have a large potential impact on the current and future capabilities of automation technologies as a whole.

Artificial Intelligence*

Artificial intelligence (AI) is a loose conglomeration of research areas united by the common goal of designing machines which can perform tasks we would generally regard as requiring intelligence. It is significant for programmable automation because many experts look to AI techniques as the key to automating parts of the manufacturing process heretofore thought to be too complex for automation.

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[37] T. Williams, Purdue Laboratory for Applied Industrial Control, "Information Systems Technology and Automation: Its Present Day Status and a Prognosis," paper developed for the American Society of Mechanical Engineers Winter Annual Meeting, Boston, Nov. 15, 1983.

*A forthcoming OTA report, "Information Technology Research and Development," will discuss artificial intelligence in more detail.

The core of basic, long-term AI research includes work on imparting such intelligent characteristics as learning, reasoning and planning to computers. Building on some of this work are several more applied research areas: the most sophisticated end of the **robotics** field; the development of systems for **image processing**—deciphering images from video cameras or touch sensors; development of techniques to allow the computer to understand **natural language** (e.g., English, as opposed to computer languages such as FORTRAN), both written and spoken; and **expert systems**, programs which can, through a sophisticated network of rules, advise or make decisions in specific situations much as a human expert would.

While robotics and sensors (image understanding) have been largely covered elsewhere in the chapter, natural language and expert systems both have significant potential applications for manufacturing in this decade.

Commercial systems for processing both written and spoken language have received substantial attention in the past 5 years. The hope for both kinds of systems is that, by allowing people to give commands and communicate with computers in everyday language, widespread use of the computer will be substantially easier. Fewer people would need to learn specialized computer languages, and fewer computer experts would be needed as intermediaries between computers and those who wish to use the computer as a tool.

The primary application for computer processing of **written language** has been in the development of so-called natural language front ends for data-base management systems (DBMS). In such a system, the data base—e.g., sales records for a company—and the DBMS itself used to manipulate and summarize that data, remain essentially the same. However, the natural language "front end" allows users to type questions in relatively free-form English, and translates those questions into the specialized language used by the DBMS.

For example, without a natural language front end, a plant manager who sought the answer to the question, "Which products in the 2000 series were sold in volumes of more than 1,000 last year?" would probably refer the question to a programer, who would write a short program in a computer language to process the request.* With a natural language feature added to the DBMS, that plant manager could type his request, more or less exactly as he would say it, into a computer terminal, and the requested information would appear on the screen.

In general, though, scientists have found natural language understanding to be a much greater challenge than originally expected. Because there are so many ambiguities and unclear references, understanding everyday language requires substantial information about the context of a given statement or question, and the world in general. Organizing such information to allow natural language understanding by computer has proven to be an extremely difficult task, in part because of our very incomplete understanding of how people store and manipulate such information.

In practice, this means that constructing a natural language front end for a DBMS requires weeks or months of work in writing code that sets forth for the computer the various meanings of the terms used for a particular application, and the possible ways they can be combined. Although many such systems can interpret relatively free-form questions, they are also severely constricted in subject area. In other words, the same system which can interpret questions about a firm's sales cannot decipher queries about the design of its products.

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*In one DBMS language, such a (very simple) program might look like:

```
OPEN SALES83:
FIND ALL
FIND PRODNO GT 1999 AND LT 3000
FIND SALESVOL GT 1000
LIST PRODNO, SALESVOL
```

Systems for computer processing of **spoken language** present a different set of problems. These involve techniques for analyzing the electronic signals produced by a human speaking into a microphone, and comparing them to signal patterns stored in computer memory. Voice recognition systems have been developed which are capable of interpreting perhaps 100 words, spoken distinctly and usually by a speaker to which the system has been "trained" to listen. Such systems can be used, for example, to allow workers to give the computer simple commands when they do not have a hand free to use a keyboard. Various other uses have been proposed for such systems, from directing the motions of a robot to operating a CAD system, although the limited vocabulary and lack of flexibility of such systems has hindered widespread use. Rapid advances in hardware and software for voice recognition may expand their capabilities in the next few years.

Both for written and spoken language understanding systems, the limited breadth and flexibility of applications is a consistent theme. In fact, a general solution to the problems of natural language understanding—e.g., one that could impart to a computer the language understanding capabilities of a 5-year-old child—is probably at least two decades off.

Finally, **expert systems** can allow the use of computers in situations normally thought to be so complex that they require human judgment or "intuition." AI researchers have found that in a narrowly defined problem area, it is sometimes possible to simulate much of the judgment of human experts by breaking down that judgment into hundreds of rules for the information to look for under different circumstances, and how to weigh that information.

Expert systems are typically composed of hundreds of rules, gathered by painstaking interviewing of human experts, about exactly how they make their judgments. The interview and development process for an expert system typically takes several years to complete, although it is becoming less time-consuming as techniques for developing the systems become more refined. The interview techniques used by expert system developers allow the systems to capture many of the subtleties of how an expert arrives at judgments.

Two of the classic expert systems, for example, are "Dipmeter Advisor," developed by Schlumberger to offer advice on oil geology, and Stanford's MYCIN, which advises doctors on antibiotic drug treatment. Figure 11 is an excerpt from the rules upon which the MYCIN system is based. The system asks the doctor a series of questions about the patient, and then offers a diagnosis and treatment (see fig. 12). It can explain the rules it used to arrive at its recommendation, and physicians can also improve the system by adding new rules.

Some of the more recent applications of expert systems, closer to manufacturing, are a system which guides mechanics in the repair of locomotives (Delta/CATS-1, developed by GE), and a system which helps configure complex computer systems (XCON, formerly "R-1," developed by Carnegie-Mellon University and Digital Equipment Corp.).

Though the commercialization of expert systems is only beginning, many industrialists have high hopes for their use in manufacturing. A myriad of applications have been proposed, including systems which could mimic the performance of a human machinist; systems for advising designers and preventing design errors; systems which would act as a linkage between manufacturing and design

Figure 11.—Sample Rule from the MYCIN Expert System

Rule 27

If 1) the gram stain of the organism is gram negative, and

2) the morphology of the organism is rod, and

3) the aerobicity of the organism is anaerobic,

Then: There is suggestive evidence (0.7) that the identity of the organism is Bacteriodes.

SOURCE: R. Davis and C. Rich, *Expert Systems: Fundamentals*, tutorial at 1983 conference of the American Association for Artificial Intelligence.

Figure 12.—Sample "Advice" From the MYCIN Expert System

```
[Rec 1] My preferred therapy recommendation is as
follows:
    In order to cover for items <1 3 4 5 6>:
        Give: GENTAMICIN
        Dose: 128 mg (1.7mg/kg) q8h IV (or IM) for 10
          days
        Comments: Modify dose in renal failure
    In order to cover for item <2>:
        Give: CHLORAMPHENICOL
        Dose: 563 mg (7.5 mg/kg) q6h for 14 days
        Comments: Monitor patient's white count

Do you wish to see the next choice therapy?
** NO
```

SOURCE: R. Davis and C. Rich, *Expert Systems: Fundamentals*, tutorial at 1983 conference of the American Association for Artificial Intelligence.

data bases; and even systems for overall factory control.

Two researchers describe the characteristics of a problem area which makes a good domain for expert systems as one where:[38]

> There are recognized experts; the experts are provably better than amateurs; the task takes an expert a few minutes to a few hours; the task is primarily cognitive; the skill is (routinely) taught to neophytes; the task domain has a high payoff; the task requires no common sense.

It is unclear in this early stage of application of expert systems just how widely applicable these tools will be. While the successes to date have been impressive, each of the current systems has been the result of many years of effort in top AI laboratories. Furthermore, they have succeeded in very carefully selected, and very carefully restricted problem areas. For example, GE's system for diagnosing locomotive problems cannot be used to diagnose automobiles, or even to diagnose different brands or configurations of locomotives without major alteration.

With current high levels of interest in expert systems, and evolving tools and techniques to streamline their development, it seems likely that these tools will be used in several areas of manufacturing. However, it is unlikely that expert systems will in the near future meet the many expectations which their recent successes have generated. It is easy both to underestimate the development effort and skills needed to construct such tools, as well as to imagine new applications in areas which are too broad or ill-defined for current technology to handle.

Sensing this problem, one recent National Research Council committee report warned of "unrealistic expectations:"[39]

> In an extremely narrow context, some expert systems outperform humans (e.g., MACSYMA), but certainly no machine exhibits the common sense facility of humans at this time. Machines cannot outperform humans in a general sense, and that may never be possible. Further, the belief that such systems will bail out current or impending disasters in more conventional system developments that are presently under way is almost always erroneous.

One of the dangers of high expectations for expert systems and other areas of AI is that if these expectations are unmet, there could be a backlash and loss of interest in AI. The field has already suffered from two or more such cycles of high expectations and loss of interest and credibility. Indeed, AI has long been an area in which claims and hopes are more prevalent than concrete successes, though current workers in this area seem to be rather more cautious.

Manufacturers are not alone in their high hopes for AI, as evidenced by Japan's recent "Fifth Generation" computer project, and DOD's new Strategic Computing project. Both of these programs are long-term, ambitious R&D in computer hardware and software in which AI plays a primary role (also see ch. 8). Another major goal of both programs is the development of "supercomputers." Though the definition of supercomputers changes as the technology develops, a current working definition is machines that can process more than 100 million instructions per second. AI and supercomputers tend to be discussed together and often confused with each other. However, though both AI and supercomputers are at the frontiers of computer science, they are essentially separate research areas at this time. It is likely, though, that future AI applications will require advanced computer architectures—not high-speed number crunchers as much as machines designed to process symbols and logic.

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[38] R. Davis and C. Rich, "Expert Systems: Fundamentals," tutorial at American Association for Artificial Intelligence 1983 annual conference, Washington, D.C., Aug. 22, 1983.

[39] Committee on Army Robotics and Artificial Intelligence, Manufacturing Studies Board, National Research Council, *Applications of Robotics and Artificial Intelligence to Reduce Risk and Improve Effectiveness: A Study for the United States Army* (Washington, D.C.: National Academy Press, 1983), p. 63.

Although the infusion of DOD funds into AI may expand and advance the field, defense applications may also continue to monopolize the small pool of U.S. AI researchers. Despite the fact that DOD is making concerted efforts to encourage commercial spinoffs from the Strategic Computing project, most of the attention of the AI R&D community will be focused on military applications rather than commercial manufacturing applications.

Much of the current wave of commercialization of AI is based on AI research done as much as a decade or more ago. In many cases, commercial applications have recently become feasible because of the continuing declines in costs of computing power. While one can expect further improvements in available AI-based tools over the next few years, these improvements may be small in comparison to this initial harvest. The more fundamental problems of AI, involving natural language systems of general applicability, versatile and unstructured machine vision, and—ultimately—generally intelligent, perhaps "learning" machines, are still very much a long-term research issue.

Standards and Interfaces

The need for standards in both languages and interfaces is strong and consistent throughout programmable automation technologies. Without standards, it is very difficult to combine equipment of different vendors, and it is more difficult to proceed incrementally toward computer-integrated manufacturing.

The demand for standardization in languages is particularly strong from users of automation devices, because of the increased confusion and need for additional training that result from the many different programing languages.[40]

More likely than one standard language for manufacturing, however, may be a set of standard languages for each application. For example, there might be a standard language for arc-welding robots, another for materials handling systems. These could be either formally adopted or de facto standards (i.e., they become commonly accepted through usage or through the influence of major vendors or users in the field). For example, many of IBM's products and techniques are treated as standards because the company has dominated the computer field. However, domination by a single firm in programmable automation systems is not as likely (see ch. 7). In addition, DOD has created many de facto standards, APT among them, through its procurement practices. It remains to be seen to what extent DOD's latest attempt at a standard computer language, ADA, will be applicable to manufacturing systems.

In addition to standards for programing languages, standards for interfaces between computerized devices will greatly facilitate integrated PA systems. The recent development of standards for "local area networks," initially aimed to connect personal computers in offices, may also be useful in the factory.[41] Such standards define the hardware connections for hooking devices together, as well as the "protocols" that ensure that different systems can interpret each others' messages. However, the content of those messages depends on the architecture of the factory—i.e., the different levels of control and the kind of information it is necessary to communicate. As discussed earlier, efficient architectures for integrated factories are only beginning to be worked out in manufacturing laboratories such as the Automated Manufacturing Research Facility at NBS.

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[40] OTA automation technology workshop, May 29, 1983.

[41] "Local Area Network Facilitates Factory Automation," *Tooling and Production,* May 1983, p. 94. These networks are based on a professional association-developed standard known as IEEE802.

Manufacturers and others often argue that premature standardization will stifle innovation. It can tend to "freeze" a technology at a particular point in its development, and discourage further innovations which may be inconsistent with the standard. In addition, there is sometimes a strategic concern that standard languages cause more competition by permitting easier combination of PA devices from different manufacturers. One NBS official has argued that parts of the computerized controllers for machine tools, for example, are technically ripe for standardization but the machine tool manufacturers do not seem to support such a move.[42]

Apart from any resistance to standards, there is the fact that implementation of standards is voluntary in the United States, which is not the case in many other countries. As a result, development of a successful standard takes years of negotiation among manufacturers and users. To complicate matters, recent court decisions[43] have held organizers of standards efforts liable if a standard can be shown to hurt a particular company. This has made progress toward adoption of standards in many areas even more cautious and slow-going.

NBS staffers contribute to standards efforts by serving on and helping to coordinate the many private sector standards committees working on automation issues. Relevant efforts are being conducted by the Electronic Industries Association, the Robotic Industries Association, the American National Standards Institute, the American Society for Testing and Materials, the Institute of Electrical and Electronic Engineers, and the International Standards Organization.

Human Factors Research

In the past few years, makers of all computerized equipment have become aware of a need to design systems for optimal usefulness and productivity for their human operators. There are various terms used to describe the focus of such efforts: "user friendly" qualities and "man-machine interface," for example.* In part to help market their equipment, computer manufacturers have found that there are steps they can take to improve the human factors aspects. Human factors experts argue that research and testing of the effectiveness of a product must be undertaken throughout its design cycle. "Human engineering, which was seen as the paint put on at the end of a project, is becoming the steel frame on which the structure is built."[44]

Although many experts agree on the importance of human factors, it has often been a neglected topic in research. It is frequently regarded as too basic for industry to examine, and too applied for university research efforts. Although DOD has pursued man-machine interaction research for decades, only recently has human factors become a subject of systematic study outside of DOD. Psychologists have developed testing procedures to help determine the human effectiveness of different designs. Recently, human factors of computer systems has become a strong and growing subfield of cognitive psychology.

Designers of programmable automation equipment have lagged behind the trend toward concern about human factors in computerized systems, in part because of the newness and small size of the market for many automation devices. In addition, some PA devices such as robots or portions of FMSs are often designed with the intention of minimal contact with humans.[45] Several systems designers have noted, in fact, that the systems with the worst human factors seem to be those which were designed to be unmanned, but later determined to need an operator or monitor. Computer-aided design is somewhat different from other PA technologies in this respect. Because of the larger size of the market and the recent attempts to develop lower cost systems for noncomputer users, CAD designers have begun to pay attention to designing systems that operators can use more easily and productively.

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[42] R. Hocken, NBS, personal communication, Aug. 12, 1983. For example, some NC controllers only understand a number to be "two" if it is written as "2". Others require it to be written as "2.000" or "2.E00". This can cause difficulty in trying to move programs from one machine to another, even if the machines ostensibly use the same language.

[43] In *American Society of Mechanical Engineers* v. *Hydrolevel Corp.* 102 S. Ct. 1935 (1982), the Supreme Court held that a standard-setting organization was liable for the antitrust violations of participants in the standards-making process when they acted with the apparent authority of the ASME.

*A variety of terms are used by researchers and industry to describe human factors and related subjects. Some others not mentioned in this section include software psychology, user science, and human-computer interaction.

[44] B. Shneiderman, "Fighting for the User," *ASIS Bulletin*, December 1982, p. 29.

[45] H. M. Parsons and G. P. Kearsley, "Human Factors and Robotics: Current Status and Future Prospects," Human Resources Research Organization, October 1981.

There are essentially two levels of human factors research. The first, sometimes known as "ergonomics," aims to make people more physically comfortable and productive while working at a machine. For example, it includes research on the ideal levels of light, color of display screen, size and configuration of keyboard, etc. A second level looks at more fundamental questions in "human-machine interface," such as how to distribute control between operator and machine, how to design software for optimum productivity, and how to maximize operator satisfaction. Most such work has been directed toward general purpose computers or word processors rather than programmable automation.[46]

These research areas are related to larger questions in industrial psychology and management concerning less tangible issues such as the impact of technology on the work environment and/or on the design of jobs. There has been little systematic work in the United States in these areas, although there is substantial research in some European countries.[47]

Sensors

The vast majority of programmable automation devices are limited in their capabilities because they are "unaware" of their environment. To use anthropomorphic terms, they do not "know" what they are doing, exactly where their parts are, or whether something is wrong in the manufacturing process.* This problem is especially acute when manufacturers hope to use PA devices to perform tasks normally performed by people. A minor adjustment or observation which would be easy and obvious for a human—e.g., righting a part which arrived upside-down—is nearly impossible with most current robots.

Hence, computerized devices that can acquire information about the environment are a lively area of inquiry. While many of these devices are used in conjunction with robots, they can also be used with other CAM equipment—e.g., NC machine tools or AMH systems—or independently. There are roughly three categories of applications for sensor systems: 1) **inspection,** in which parts or products are examined and evaluated according to preestablished criteria; 2) **identification,** in which parts, products or other objects are classified for purposes of sorting or further processing; and 3) **guidance and control,** in which sensors provide feedback to robots or other CAM devices on their position and the state of the part or product.

One can simplify the range of sensor technologies by dividing the devices into three classes according to their complexity. While all of the devices are used for guidance and control applications, usually only the most complex (i.e., vision and touch sensors) can handle inspection and identification tasks.

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[46] There has been substantial work, however, in the design of systems for teleoperators—remote manipulators controlled by a human operator. Such work is often aimed for ultimate applications in unmanned space missions or underseas, handling of radioactive material, or battlefield applications. See, for example, T. N. Sofyanos and T. B. Sheridan, *An Assessment of Undersea Teleoperators* (Cambridge, Mass.: MIT Sea Grant College Program, June 1980).

[47] See, for example, H. H. Rosenbrock, Professor of Control Engineering, University of Manchester (U.K.) Institute of Science and Technology, "Robots and People," *Measurement and Control,* March 1982, pp. 105-112; P. Brödner and T. Martin, "Introduction of New Technologies into Industrial Production in F. R. Germany and its Social Effects—Methods, Results, Lessons Learned, and Future Plans," *Proceedings of the Eighth Triennial World Congress of the International Federation of Automatic Control,* Kyoto, Japan, Aug. 24-28, 1981, pp. 3433-3445; Swedish Work Environment Fund, *Programme of* Activities and Budget, 1981/82—1983/84. For further detail see ch. 5.

*There are some exceptions where PA devices do have significant information about their environment. One obvious exception is the Coordinate Measuring Machine, built specifically to measure the dimensions of objects. Another is in factories which code each part, for example, with optical codes similar to those used on groceries. Optical code readers at each machine can identify the part in process. Finally, many PA devices do have *internal* sensors. For example robots and machine tools have sensors which provide feedback on the positions of their joints.

The simplest devices provide binary information—e.g., a weight sensor, photocell, or simple electrical switch can indicate whether a part is or is not present. These simple sensors are relatively cheap, technologically mature and easy to implement. They are already used widely in manufacturing equipment, and their use will undoubtedly continue to grow for applications in which binary information is useful.

At a moderate level of complexity, the information sensed is analog (continuously varying). For example, a proximity sensor can determine the distance of an object. A popular proximity sensor used as a safety device on industrial robots is the same as the one used on Polaroid SX-70 cameras. It calculates distance by emitting inaudible sound waves and calculating how long they take to bounce off the closest object and return. For safety purposes, these can be used to stop the motion of the robot if a human enters its "work envelope." Other sensors in this moderate level of complexity include devices which can electromechanically sense force and torque—e.g., in a robot arm or a machine tool spindle. These can be used, for example, to allow a robot gripper to apply just enough force to a delicate object. Finally, many devices for measurement fall into the moderate-complexity category. Optical sensors, for example, can be used to monitor the diameter of a driveshaft on a lathe, or for noncontact sensing of the dimensions of hot metal as it emerges from forging processes.

Most of these moderately complex sensing techniques are fairly well-developed, and can be applied relatively easily albeit with some customization. There is a moderate amount of R&D under way to increase the quality of information from these devices (e.g., their sensitivity and speed), and to increase their range of applicability (e.g., development of sensors for measuring arbitrary prismatic shapes on machine tools). In addition, the coordination of these sensors with each other and with CAM tools is a very difficult problem. Computer scientists are attempting to develop processing techniques that can quickly interpret force and torque data from the various joints of a robot, for example, and provide feedback to the robot's controller.

At the most sophisticated end of the sensing techniques, visual and touch sensors deal with information that is not only analog but also needs substantial processing to be useful. Vision and touch sensing technologies are only in their infancy, and have just begun to have practical uses in the factory. Of the two, vision by far receives the most attention.

The chief technical problem in machine vision systems is in interpreting the pictures generated by a video camera. In a typical vision system, a frame—i.e., one complete image frozen in time— is typically composed of 256 by 256 picture elements, or pixels. If each pixel is either black or white, then there are more than 65,000 bits of information that the computer program must process. In general, the steps in the process include:[46]

- *Segmentation.*—The areas of the image must be clarified and divided into segments or "blobs," representing the features of the object and its background. There are two general schemes for beginning the interpretation of the data. One makes use of discontinuities—primarily detecting the edges of the object in the image. The other approach relies on similarities in the image, i.e., areas of the image that are of similar intensity.
- *Recognition.*—The system must compare the features (segments) it has identified with those stored in its memory, attempt to find an object in its memory that is suitably close to the one in the image, and hence label the object and its features.
- *Interpretation.*—This step varies depending on the machine vision application. For

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[46] J. M. Wright, "Vision of the Future," unpublished manuscript, Carnegie-Mellon University Robotics Institute, January 1983.

robot guidance, the interpretation step might be to identify the object, then calculate its coordinates so that the robot can grasp it. For an inspection application, the interpretation of the image might be to determine whether the object has the right dimensions or is free of defects.

In the vast majority of current vision systems, each picture element in the 256-by-256 element image is either black or white. In more advanced systems just beginning to be used in industry, each pixel can be one of several shades of gray. These systems, often called "gray-scale," are potentially more powerful in their ability to identify objects and cope with uneven lighting, but they also require much more computer power and algorithms for processing data which are only beginning to be worked out. Systems for processing color images are another order of magnitude more complex, and there is no active work on such systems yet.

The systems described above essentially provide 2-D information, although certain tricks can be used to infer the 3-D characteristics of an object. Some researchers have used more than one camera in order to obtain 3-D information much as the human eye does, though such schemes are in very early stages. One very promising method to obtain 3-D information is the use of "light striping" systems. In such a system, a laser or other light source flashes a very precise band of light onto an object, and the camera records the image at that instant. By examining how such structured light bends over a 3-D object, the system can infer the dimensions and distance of the object.

Current machine vision is in a very early stage. The range of objects that can be iden-

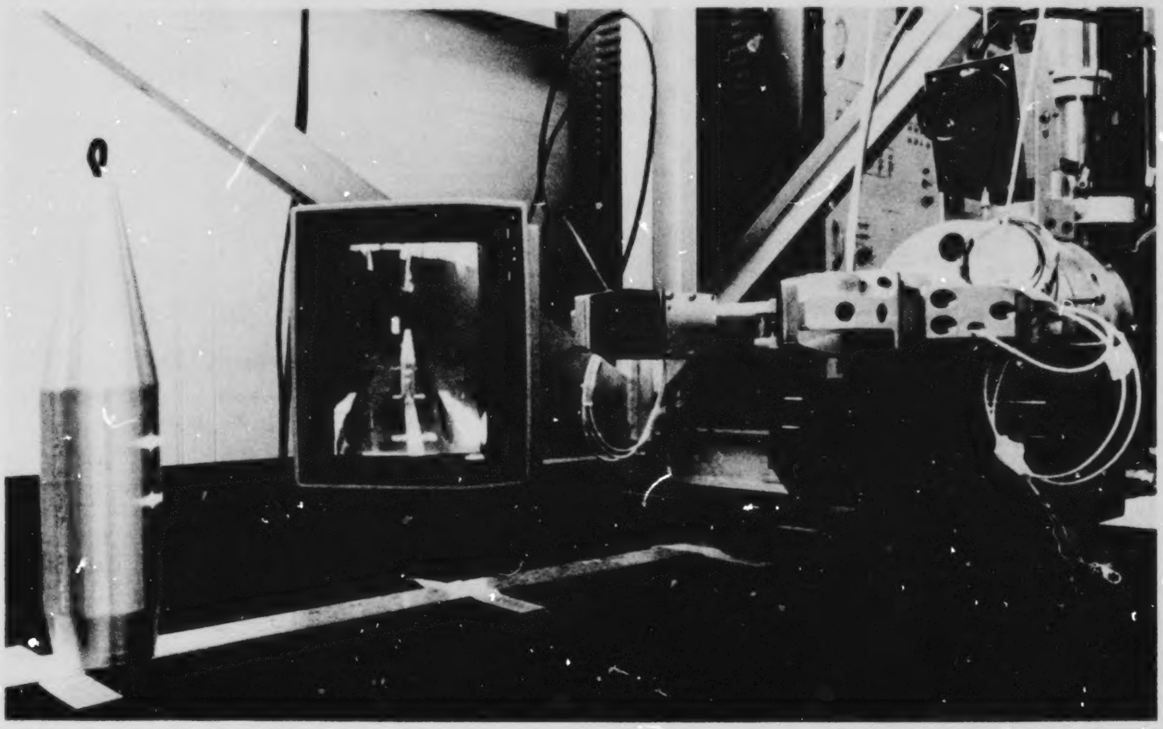


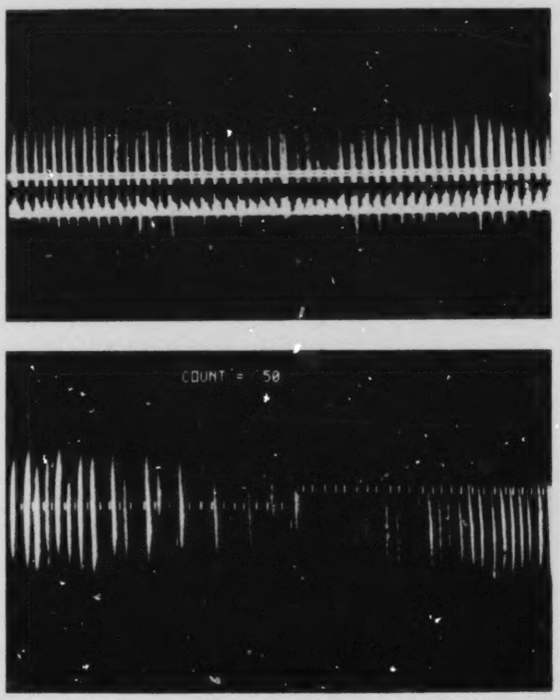
Photo credit: National Bureau of Standards

"Light striping" system can determine the shape of a 3-D part by flashing a very precise line of light (from slots on right, below gripper) and photographing how that light is bent by the object. TV monitor shows view of camera above gripper tified, the speed of the interpretation, and the susceptibility of the systems to lighting problems and minor variations in texture of objects are all examples of serious problems with current technology. Successful applications of current machine vision technology tend to be very specific, ad hoc solutions, often using clever "tricks" or manipulations of the manufacturing environment. As one report notes, "The vision systems of today, and those for the rest of the decade will not promise great generality. These sorts of tricks will be an important part of the field for many years to come."[49] Nevertheless, many useful applications are possible with existing technology and machine vision is currently a rapidly growing field. In certain specific applications, especially very tedious tasks such as inspection of electronic circuit boards, machine vision systems can outperform humans.

An example of a successful machine vision application is shown in figure 13. Here, a system developed by Octek Corp. counts stacks of cups prior to packaging. The system first "grabs" an image from its camera under controlled lighting conditions, defines the edges of the cups, attempts to eliminate shadows and other confusing data, and counts the number of cup lips. Similar programs have been developed to inspect cassette tapes and circuit boards.[50]

While there is considerably less research effort under way on touch sensors, there are several groups of researchers, for example, working on a touch sensor based on a carbon-impregnated rubber pad which changes its electrical conductivity under pressure. This pad could be attached to a robot's gripper, and it would send to the computer processor an image or "footprint" of the object being grasped. Once this image has been obtained, interpreting it involves virtually the identical process used for vision processing.

Figure 13.—Machine Vision Process



Two steps in a machine vision process developed to count stacks of paper cups for a cup manufacturer. The cups are lit by a highly directional fiber optics light source, which makes their edges stand out. The top photo shows part of the system's segmentation process, in which it assesses the intensity of light for each cup lip. The bottom photo indicates the interpretation function, in which the system has counted the number of cups in the stack. Note the shadows and relative unevenness of light which complicate even this simple machine vision application.

SOURCE: Octek Corp.

There seem to be two schools of thought on sensors for industrial robots. One argues that, if enough care is taken in organizing the manufacturing environment, complex sensors are unnecessary. Parts can be carefully fixtured so they are in the proper orientation and position, and sensors in the simple or moderate levels of complexity will suffice. The other point of view is that robots should be able to adapt to the chaos of manufacturing, and should ideally have senses—vision, in particular—which rival those of a human.

Materials Trends

Plastics, ceramics, and composites are replacing metals in a wide variety of products at an increasing rate. This trend is both complementary to and problematic for increased use of certain PA devices.

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[49] Ibid.

[50] D. L. Hudson and J. D. Trombly, "Developing Industrial Applications for Machine Vision," *Computers in Mechanical Engineering*, vol. 1, April 1983, pp. 18-23. Note that this application of machine vision, like many inspection applications, is not used in connection with a robot.

These new materials technologies, on the whole, fit well into an environment of computer-integrated manufacturing. Injection molding of plastics, for instance, is by nature an automated process and adapts easily to integration with other computer-controlled devices. It is thus possible to create a "flexible manufacturing system" for plastics at least as easily as for metals.* Similar systems are also possible for producing parts from new-technology "fine grain ceramics," which have strength comparable to that of metal (at a fraction of the weight), are immune to corrosion, and do not have the brittle qualities that one expects from ordinary ceramics.

These trends and others mean that the amount of metal-removing activity is going to decrease. Thus, there is some chance that use of plastics and ceramics will eventually render obsolete some new metalcutting equipment. This possibility has not yet been examined systematically by the metalworking community. Robots, because of their flexibility, are less likely to be affected than machine tools. However, there are certain factors that tend to make widespread obsolescence of new metalworking equipment unlikely. First, metalworking machines have useful lives of 30 years or more, and the users of this equipment move notoriously slowly in replacing machine tools. As new materials technologies do reduce the amount of metalworking, it is the vast stock of older, manual machine tools that is likely to be useless rather than the newer equipment. Second, it is expected to take at least two decades for ceramics to displace a significant amount of metalworking.

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*One hitch in creating an FMS for plastics is in developing dies (the metal forms into which molten plastic is injected) which are "programmable" or easily changed. Several researchers are currently working on this problem.

Future of the Technologies

Capabilities

Building on the "Trends and Barriers" section of this chapter, tables 11 through 15 summarize the main problems for PA technologies and the projected times for solution. Though these projections must be considered extremely tentative, they provide a sense of the relative scale and complexity of the problems.

Because the amount of time between laboratory solution of a problem, first prototype applications, and the widespread and easy availability of that solution is significant, the tables include a separate estimation of each. Projections for applications and availability are even rougher than the projection for a technical solution, since they depend on many social, economic, and market conditions.

These projections were compiled by analysis of existing sets of projections[51] and by interviews with technology experts. Projections of technological developments are inherently controversial, and experts do not always agree. Some experts will view these estimates as either too optimistic or too pessimistic. During the interviews with technology specialists, for example, several pointed out that some of the "key problems" listed in the table may

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[51] See, for example, Manufacturing Studies Board, National Research Council, *Applications of Robotics and Artificial Intelligence to Reduce Risk and Improve Effectiveness: A Study for the United States Army* (Washington, D.C.: National Academy Press, 1983); R. E. Garrett and R. M. Mueller, "Strategic Analysis/Technology Trend Report," Control Data Corp., May 15, 1981; D. Grossman and J. T. Schwartz, "The Next Generation of Robots," in *Frontiers in Science and Technology* (Washington, D.C.: National Academy of Sciences, 1983), pp. 185-209.

Table 11.—CAD: Projections for Solution of Key Problems

	Current (1984)	1985-86	1987-90	1991-2000	2001 and beyond
Hardware:					
1. High-resolution, color display of designs, with rapid generation of images[a]	▲	●	■		
Both hardware and software:					
2. Low-cost, powerful microcomputer-based workstations for:[b]					
a) electronics design	▲	●	■		
b) mechanical design		▲	●	■	
3. Independent CAD workstations linked by network, with access to supercomputer for powerful analysis and simulation	▲	●	■		
Software:					
4. Three-dimensional solid modeling systems, resulting in:[c]					
a) more realistic images	▲ ●		■		
b) enhanced ability to connect with manufacturing equipment	▲		●	■	
5. Comprehensive, powerful computer-aided engineering systems[d] for mechanical design			▲	●	■
6. Extensive design/manufacturing integration[e]		▲	●	■	

[a] While color displays are currently available, they tend to sacrifice either resolution (the fineness and clarity of the picture) or the speed with which the images can appear on the screen. New techniques for displays, such as the use of dedicated microprocessor chips (sometimes termed "silicon engines") to generate images, promise to improve this situation.

[b] Microcomputer-based workstations for CAD are now being marketed, but in the judgment of technical experts consulted by OTA, they are either not powerful enough and/or not inexpensive enough to be useful in a wide variety of applications.

[c] CAD experts report that many systems for 3-D solid modeling are available now, but they are not being used because of their large appetite for computer power, and because their capacity to link design data to manufacturing equipment is inadequate. Part (b) of this entry refers to this ability to store and manipulate design data about the physical characteristics of a part in such a way that it can be transmitted to manufacturing equipment with only minimal intermediate steps.

[d] This entry refers to modules powerful enough to allow extensive interactive testing, simulation and refinement of designs in a wide range of applications. Such systems are strongly product-dependent; while they may be near available for certain products now (e.g., integrated circuits, certain portions of aircraft and motor vehicles), they are much less advanced in other industries and applications.

[e] This entry denotes the "window from design to production" which would, for instance, allow designers to examine the production implications of design choices. These include the costs and necessary production processes, as well as the history of manufacturing similar items at the plant. Such comprehensive connections would allow much more substantial integration of CAD, CAM, and computer-based management.

▲ = solution in laboratories.
● = first commercial applications.
■ = solution widely and easily available (requiring minimal custom engineering for each application).

SOURCE: OTA analysis and compilation of data from technology experts.

never be solved at all—the development of standard languages for robots (table 12 item 10) for example, depends as much on market factors and political considerations among robot vendors and users as it does on technical issues. Similarly, development of artificial intelligence-based systems which could control much of a factory without human intervention (table 15, item 5) depends on fundamental advances in the field of artificial intelligence that are by no means assured.

On the other hand, it is possible that some of the advances in the accompanying tables may occur significantly faster than the tables indicate. This might be particularly likely if the Federal Government and/or industry were to choose to make dramatic increases in R&D funding for PA technologies. Chapter 8 discusses R&D funding in more detail.

However, industry observers report with virtual unanimity that the application of programmable automation in most industries is lagging significantly behind the technologies' development, and that there appear to be abundant, relatively easy opportunities for use of current automation technologies. Hence the main stumbling blocks in the near future for implementation of PA technologies are not technical, but rather are barriers of cost, organization of the factory, availability of ap-

Table 12.—Robotics: Projections for Solution of Key Problems

	Current (1984)	1985-86	1987-90	1991-2000	2001 and beyond
Hardware:					
1. Lightweight, composite structures and new forms of drive mechanisms	▲	●	■		
Both hardware and software:					
2. Force sensors	▲ ●		■		
3. Versatile touch sensors		▲	●	■	
4. Coordinated multiple arms		▲	●	■	
5. Flexible, versatile grippers			▲	● ■	
Software:					
6. Precise path planning, simulation and control with CAD	▲		●	■	
7. 3-D vision in structured environments which have been planned to simplify the vision task	▲ ●		■		
8. 3-D vision in unstructured complex environments which have not been planned to simplify the vision task			▲	●	■
9. Robust mobility in unstructured environments			▲	●	■
10. Standards clarifying different versions of robot languages, and helping ensure a common language for similar applications			▲ ●	■	

▲ = solution in laboratories.
● = first commercial applications.
■ = solution widely and easily available (requiring minimal custom engineering for each application).

SOURCE: OTA analysis and compilation of data from technology experts.

Table 13.—NC Machine Tools: Projections for Solution of Key Problems

	Current (1984)	1985-86	1987-90	1991-2000	2001 and beyond
Hardware:					
1. Systems which can automatically and reliably remove a wide variety of metal chips produced in cutting[a]			▲	● ■	
Both hardware and software:					
2. Reliable, widely applicable adaptive control to optimize speed of metal removal	▲		●	■	
3. Tool wear sensors applicable to wide range of cutting tools	▲	●		■	
4. Systems for measurement of parts of a variety of shapes and sizes while the parts are being machined		▲	●	■	
Software:					
5. Controllers to accommodate ties to robots	▲	●		■	
6. Model-based machining in which the machine tool operates substantially automatically based on data about metal processes and the part to be produced		▲	●		■
7. Widely applicable 3-D verification of NC programs using CAD-based simulations		▲		●	■

[a] Systems currently exist for automatic removal of metal chips, but despite much interest and research, they are neither very reliable nor generically applicable (i.e., they can only be used for certain kinds of metals or cutting processes).
▲ = solution in laboratories.
● = first commercial applications.
■ = solution widely and easily available (requiring minimal custom engineering for each application).

SOURCE: OTA analysis and compilation of data from technology experts.

Table 14.—FMS: Projections for Solution of Key Problems

	Current (1984)	1985-86	1987-90	1991-2000	2001 and beyond
Hardware:					
1. Generic fixtures for holding a variety of work-in-process parts		▲		● ■	
Both hardware and software:					
2. FMS for:[a]					
a) cylindrical parts production	▲ ●			■	
b) sheet metal parts production	▲ ●			■	
c) 3-D mechanical assembly	▲			● ■	
d) electronics assembly	▲ ●		■		
3. Materials handling systems which can handle a variety of parts in any sequence necessary	▲ ●		■		
Software:					
4. Automatic diagnosis of breakdowns in the FMS			▲	●	■
5. Standardization of software interfaces between computerized devices in an FMS			▲	●	■

[a] Almost all FMS currently running are used to machine prismatic parts, (e.g., engine blocks) which are those whose outer shape consists primarily of flat surfaces. The projections in this entry refer to FMS for quite different applications: a) machining of cylindrical parts, such as rotors and driveshafts (or "parts of rotation," in machining jargon, since they are generally made on lathes); b) stamping and bending of sheet metal parts, such as car body panels; c) assembly (as opposed to fabrication of individual parts) of three-dimensional products, such as motors; and d) assembly of electronic devices, such as circuit boards. While machines currently exist for automatic insertion of electronic parts into circuit boards, an electronics FMS would integrate the insertion devices with soldering and testing equipment.

▲ = solution in laboratories.
● = first commercial applications.
■ = solution widely and easily available (requiring minimal custom engineering for each application).

SOURCE: OTA analysis and compilation of data from technology experts.

Table 15.—CIM: Projections for Solution of Key Problems

	Current (1984)	1985-86	1987-90	1991-2000	2001 and beyond
Software:					
1. Well-understood, widely applicable techniques for scheduling and logistics of complex materials handling systems that would allow full factory integration			▲	●	■
2. Standard communication systems (networks)	▲	●		■	
3. Standardization of interfaces between wide range of computerized devices in an integrated factory			▲	●	■
4. Data base management systems which could sort, maintain and update all data in a factory				▲ ●	■
5. Computerized factories which could run on a day-to-day basis with only a few humans in management, design functions					▲

▲ = solution in laboratories.
● = first commercial applications.
■ = solution widely and easily available (requiring minimal custom engineering for each application).

SOURCE: OTA analysis and compilation of data from technology experts.

propriate skills, and social effects of these technologies. These issues are more fully addressed in later chapters of this report.

Many in industry would argue that CIM is inevitably the future of manufacturing. Its advantages in cost, quality, flexibility, and control will, they assert, mandate its adoption. Many parts of computer-integrated manufacturing can be put together on an ad hoc basis now, and as the tables show, prototype solutions for many of the key problems already exist. However, several key aspects of the puzzle are as yet unsolved (the development of interface standards for computerized tools, in particular), and for CIM to be practical each of its elements must be mature, versatile, and relatively easily available commercially.

As noted earlier in this chapter, CIM does not necessarily imply manufacturing without humans. In fact, one of the biggest challenges on the road to CIM is learning to use humans in effective ways, to develop machines with which humans can work effectively, and to identify the points in the production process where maintaining human involvement may enhance flexibility, responsiveness, diagnostic power, and creativity. The extent to which that effective use of people in manufacturing will develop, and the extent to which CIM will remove humans from manufacturing environments, are still open questions.

Automation technology researchers report progress on virtually all of the technical problems, although the degree of progress often depends on research funding, commercial demand for related products, and inclinations of researchers. The technical barriers to increased sophistication in programmable automation are largely due to the complexity of the manufacturing environment, and to the fact that many manufacturing processes—e.g., machining, scheduling, design—have not been clearly understood in a way that can easily be computerized.

These projections of future technical capabilities, along with various other projections, imply that the remainder of the 1980's will be a time when applications will to some extent catch up with developed PA tools. Some technical improvements will doubtless be made during this time. But most prognosticators seem to see the 1990's as a period when the application of basic PA tools will become widespread, and a number of major technical improvements will be available, particularly for robots and FMSs (see tables 12 and 14). While this may, in some cases, suggest that the 1990's seem far enough away to solve almost any technical problem, it also seems to indicate that the next decade will bring quite substantial increases in the power and potential uses of programmable automation.

Future Levels of Use of Programmable Automation

The rate of growth in use of programmable automation in the United States, known as the "diffusion" of the technologies, depends on factors both in the larger economy and at the level of individual firms and products. Some of the more general factors include availability of capital and skilled labor, international competition, and the amount of attention American firms devote to improvements in manufacturing processes. The last factor may be the most critical. Manufacturing engineering in the United States has been largely neglected both in engineering schools and in industry.[52]

Prompted in part by international competition, however, the mood among American industrialists (to the extent there is a "mood" in such a diverse group) seems to be changing. Increasingly, established management practices are being questioned in conferences and industry journals, and many industrial managers are closely examining improvements in manufacturing processes, particularly robots.* The extent to which this change in mood will effect lasting and significant change in manufacturing, however, is uncertain. Many management specialists believe that such lasting change must include discarding powerfully entrenched habits in industry, particularly financially-oriented management strategies that discourage risk-taking and downplay quality relative to cost.[53]

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[52] See, for example, E. N. Berg, "Manufacturing's Academic Renaissance," *The New York Times*, Oct. 30, 1983.

*Despite the generally rising interest in robotics, a significant group of people remain powerfully skeptical about the use of robots as one of the primary steps to enhance productivity. In a 1983 survey by the Institute of Industrial Engineers, for example, members of the society—who are closely involved with manufacturing processes on a day-to-day basis—rated robotics relatively low in effectiveness of a group of productivity-

In addition to these more general questions, a large number of factors come into play when an individual firm chooses to use or not to use programmable automation. Some of the technical factors include: the applicability of the technology to the problem at hand, which tends to vary according to the particular manufacturing processes used in each factory; the range of tasks to which a given tool can be applied; the cost of customization, particularly for new technologies where few standards exist and almost every application is a prototype; the ease of use of the tool; the reliability of the equipment; the compatibility of programmable automation with machines already in place; and finally, the capacity of different PA systems for upgrading and expansion.

Organizational factors can also have a significant effect on firms' automation decisions. For example, one researcher found that previous experience with automation was a key factor in successful applications,[54] and industry observers report that many unsuccessful attempts to use programmable automation have been due to premature jumps into complex systems. There can also be substantial resistance to change on the part of workers or management. Many manufacturers report, however, that production workers tend to accept technological changes such as automation, while strong resistance tends to come from middle managers who fear programmable automation will diminish their degree of control or eliminate their jobs.[55] Chapter 5 discusses organizational issues of PA implementation in more detail.

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enhancing methods. Only 29 percent had undertaken increased use of robotics in the past 5 years; 22 percent rated the step high in effectiveness, 48 percent moderate, and 26 percent low. Measures which received higher effectiveness ratings included capital investment for new or automated machinery generally, worker training, improvement of inventory control, and "systems innovations." The interpretation of these survey results could differ; some would argue that increased familiarity of industrial engineers with robotics will lead to higher perceptions of effectiveness. In addition, robotics was not viewed as unproductive by very many respondents; it simply appeared not to be the productivity tool of first choice. (See "Productivity Today: An Inside Report," The Institute of Industrial Engineers, Norcross, Ga.)

[53] See, for example, R. H. Hayes and W. J. Abernathy, "Managing our way to econonic decline," *Harvard Business Review*, July-August, 1980, pp. 67-77.

[54] J. Fleck, "The Adoption of Robots," *Proceedings of the 13th International Symposium on Industrial Robots and Robots 7*, Apr. 17-21, 1983.

[55] OTA Automation Technology Workshop, May 29, 1983.

Chapter 4

Effects of Programmable Automation on Employment

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Chapter 4

Effects of Programmable Automation on Employment

Summary

Employment change due to programmable automation (PA) will not be precipitous. Programmable automation will depress the number of jobs available in manufacturing, but it will not necessarily cause significant national unemployment during this decade or even the next. By eliminating specific tasks and by contributing to major changes in manufacturing processes and organizations, PA will "displace" jobs (where jobs are defined as sets of tasks performed by individuals working a standard number of hours). Whether unemployment occurs depends not only on these displacement effects, but also on the level of production volume (which depends on foreign trade and consumer demand), and on the numbers and types of people seeking work.

Slower growth in the labor force, increases in capital goods production, and limited or imperfect use of PA technology are among the factors likely to buoy manufacturing employment during this century. However, regional and local employment may suffer due to the combined effects of labor-saving technology, import competition, and other factors, especially where area economies depend on so-called declining or mature industries. Yet PA may help firms in those industries employ more people than they might otherwise—at least to the extent that it makes them more competitive. Cumulative experience and improvements in technical capabilities and costs should increase the use of PA (and its employment effects) during the 1990's relative to the 1980's.

Programmable automation will reinforce the ongoing trend toward increased "white collar" or salaried employment and increased service industry employment, although skill requirements for jobs at all but the highest levels in manufacturing may fall. Producers of PA are particularly likely to employ predominantly salaried personnel, especially if they continue to import significant amounts of PA hardware from overseas. Consequently, there will be few opportunities for people to move directly from production jobs where PA is used to jobs producing PA. Also, the limited amount of actual production work expected among PA industries is one reason OTA expects that job creation among producers of PA equipment and systems will be less than job loss among users.

Programmable automation will blur distinctions between occupational categories and present vast opportunities for restructuring jobs. Among occupational groups, technicians will become more prominent with the spread of PA, in part because they will perform tasks otherwise performed by engineers or skilled tradesmen. Engineers will nevertheless constitute a growing share of manufacturing employment, as may mechanics, repairers, and installers. Operatives, laborers, and production-clerical personnel are the most vulnerable to displacement.

PA will provide new opportunities for structuring jobs because of its tendency to displace and to create individual tasks. It therefore raises questions about the tradeoff between large numbers of narrowly defined jobs—customary in manufacturing to date—and smaller numbers of more broadly defined jobs. How and whether the potential for positive change in job design and the organization of work is realized depends on decisions by individual managers. Many factors—e.g., the operating speed of automated equipment, the breadth of functions it can perform, and the reduction in average skill requirements some users may experience—may cause a problem of overconfidence in programmable automation. There is a risk that users may too readily assume that the computer knows best, overlooking the value of experience-based understanding of manufacturing processes.

Introduction

The elimination of jobs will be a principal long-term effect of programmable automation: PA technologies are designed to reduce labor hours in production. They are sold as labor substitutes, whether or not the total number of employees will actually fall with their use. Even the advertising language emphasizes the capacity of machines to emulate or improve on human performance (e.g., "the graphics lathe control that thinks like a machinist"). In addition to its impacts on the number of jobs, programmable automation will also bring about major changes in job content and job mix in the manufacturing workplace. All of these effects will occur not because of technological change alone, but because of concomitant changes in how companies are organized and managed and in what and how much they produce.

This report does not examine employment change exhaustively.* Doing so would require a thoroughgoing examination of changes in the structure of the economy and individual industries. The report does, however, show how one set of technologies (which can be used across an unusually broad range of industries) may alter demand for labor. It shows that **programmable automation creates enormous potential for change in the use of labor.** Not only will it reduce the amount of labor used to produce a given amount of product, it will also motivate shifts in the mix of personnel and in the services sought from employees. PA will directly or indirectly affect all types of personnel, professional and technical as well as production and clerical.

Despite this broad potential for change, **no one set of impacts is inexorable.** PA and other factors (e.g., changes in consumer demand and in the business relationships between firms) will present employers with choices about the number and types of personnel they use. The outcomes of those choices will determine future staffing patterns and employment levels in firms and industries.

Prior to examining the employment effects of programmable automation, it is useful to review some basic labor market characteristics and analytical concepts. In the aggregate, changes in industry or national employment levels depend principally on economic conditions, including both short-term cyclical conditions and more profound structural changes in the economy. These conditions reflect changing buying patterns of consumers as well as the investment decisions of companies and Federal budget policy (which affects the financial resources of individuals and businesses). The numbers and types of jobs depend heavily on the numbers and types of goods and services consumers demand and on the countries from which they buy them. For this reason, import (and export) levels—which reflect preferences for foreign products relative to domestic ones—are an important determinant of employment.

Technology used in production is a secondary influence that is dwarfed by the effects of demand changes; it governs the mix of labor and other inputs. Technology change generally affects employment much more slowly than do demand shifts, because it does not affect an industry or an economy all at once. Automation, in particular, is typically adopted during periods of economic expansion, a timing that facilitates the adjustment of work forces through attrition.*

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*For additional treatment of employment change, see upcoming OTA assessments on technology and structural unemployment; technology, innovation, and regional economic development; and economic transition.

While it is hard to attribute past employment growth to a single technology change, the introduction of new products and production processes has historically been associated with employment growth. This has occurred despite the fact that productivity improvement (due to technology or other factors) by itself—i.e., unaccompanied by change in production volume or in the average number of working hours per job—will result in fewer jobs.**

The fact that interest in automation has grown during two closely spaced recessions tends to confuse the perceived relationships between automation and employment. Many employers laid off personnel because of the recessions, as is usual; what is unusual is that some may not rehire to pre-recession levels because of recent or planned automation, and/or because of permanent declines in their business. Thus, the percentage of unemployment due to permanent separations (as opposed to layoffs and other factors) grew during the last recession. These developments will likely slow the return of the unemployment rate to pre-recession levels.[1] On the other hand, because of the recessions and recent high interest rates many firms avoided investing in new equipment. The recovery may outpace their ability to automate, or it may fail to generate sufficient profits for them to automate.

The auto industry exemplifies all of these possibilities to some degree. Yet it was widely recognized before the recent explosion of interest in robots that U.S. automobile manufacturers were unlikely to hire to prior peak levels anyway, at least during the 1980's, because of changes in the auto market, such as growth in imports.[2] In some industries, such as autos, PA may help to preserve jobs by helping domestic firms repel import competition, although total industry employment may fall.*

Changes in employment levels will depend not only on how technology and economic conditions affect industries immediately involved in producing and using the technology; they will also depend on how related industries (e.g., suppliers and customers) are affected. Evaluation of both direct and indirect employment effects generally requires a macroeconomic model that captures interindustry links and their sensitivity to changes in prices and technologies. At this time, available data are not adequate to fully model the likely impacts of PA.

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*These points are frequently raised by the Bureau of Labor Statistics. Also, West German research shows that on an overall industry level, the timing of adoption of automation, relative to when it is first introduced, affects the rate and level of employment change. A West German study found that the actual and hypothetical employment reductions associated with numerically controlled (NC) machine tools fell between 1973 and 1979; actual layoffs were negligible. The authors concluded that the potential for displacement depended on where the technology was used: compared to the early ones, later NC investments were aimed at replacing old equipment rather than expanding capacity, and such installations were more common among relatively small users, where the opportunity for productivity improvement (and displacement) was lower.

As that study illustrates, estimates of potential displacement should allow for change in baseline conditions over time. Another German study estimated that, when used as an alternative to stand-alone NC, newer flexible manufacturing system (FMS) technology could displace 1,000 to 3,000 people by 1990, or less than 1 percent of metalworking employment. The authors concluded that organizational inertia and difficulties involved in using the relatively new technology would retard actual displacement. The conclusions drawn in these studies are consistent with the expectations of analysts who are familiar with American use of NC and FMS. See Werner Dostal, et al., "Flexible Manufacturing Systems and Job Structures" (Mitteilungen aus der Arbeitsmarkt- und Berufsforschung), 1982; and Werner Dostal and Klaus Kostner, "Changes in Employment With the Use of Numerically Controlled Machine Tools" (Mitteilungen aus der Arbeitsmarkt- und Berufsforschung), 1982.

**OECD, for example, has estimated that if productivity were to rise 10 percent between 1980 and 1990 and world trade failed to grow over the decade, aggregate employment would be 0 to 4 percent lower than in 1980. However, OECD believes that the higher estimate is unrealistic, because such productivity growth would be unusually high, permanent increases in productivity growth rates are unlikely, and static trade is especially unlikely. *Microelectronics, Robotics and Jobs*, OECD, Paris, 1982, p. 90.

[1] Robert W. Bednarzik, "Layoffs and Permanent Jobs Losses: Workers' Traits and Cyclical Patterns," *Monthly Labor Review*, September 1983.

[2] See *Increased Automobile Fuel Efficiency and Synthetic Fuels: Alternatives for Reducing Oil Imports* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-E-185, September 1982).

*For reference, note that Arthur D. Little concluded from a study of West European auto manufacturing that, despite an anticipated $40 billion investment in programmable automation during the 1980's, the West European share of the world auto market will continue to fall, and its employment capacity may fall by as much as 30 percent from current levels. See Martyn Chase, "European Car Makers Seen Installing $40 Billion in Automation Equipment," *American Metal Market/Metalworking News*, Feb. 28, 1983.

A major advance in this direction comes from a study recently conducted at New York University. It concluded from an input-output analysis that, given the likely impacts of several computer-based technologies on labor requirements in manufacturing, education, health, and the office workplace, and given the employment generated by increased production of computerized equipment, significant unemployment during this century is not likely to result from progressive computerization (provided that the work force can satisfy shifting occupational and sectoral requirements).

That study illustrates how employment in manufacturing can be stimulated through this century by the production requirements of potential rates of installation of computers and automation into the manufacturing and office environments. The study underscores the important role that domestic production of capital goods—demand by businesses for the products of other businesses—plays in maintaining domestic employment levels. It also shows that slower growth in the labor force can blunt the employment effects of labor-saving technologies. As the authors note, additional work is needed to assess the effects of other factors on employment, such as possible changes in production materials, in level and manner of equipment integration, and in trade patterns.[3]

OTA shares the view that use of programmable automation can grow, as is expected, without large increases in national unemployment during this century. The effects on employment of labor-saving technologies can be offset in the aggregate by changes in the labor force, as well as by likely increases in output for capital goods and other products. Such output growth, of course, assumes a strong economy. However, the transition in industry structure and occupational profiles accompanying PA and recent growth in imports may burden individuals and communities at least temporarily, especially if PA use grows more quickly and extensively than appears likely during this decade. Changes in industry demand for specific skills will make it harder for some individuals to find or change jobs, as will regional dependence on specific industries. Thus, PA may aggravate ongoing local unemployment. While the Nation as a whole will benefit from the productivity gains expected from PA, it will not benefit fully if otherwise productive labor resources are idled for long periods of time.

Analysis of the employment impacts of programmable automation is fraught with difficulty. Briefly, analysts generally approach the problem from two perspectives: the engineering approach, which focuses on the potential for equipment to substitute for people on a task-by-task basis; and the economic approach, which derives employment estimates from models of the interaction among industries based on their requirements for labor and other production inputs. Both approaches have shortcomings.[4] Moreover, the number of different PA technologies, the range of equipment designs and implementation strategies, and uncertainties about the speed and success of technical advances make the formulation of general rules about job loss (or creation) risky. So, too, does existing variation among employers (even in the same industry) in job mix, job definition, and adaptability to change. Finally, data describing prevailing skill requirements, jobs, and job mixes among firms are limited. As the technical memorandum published during the course of this assessment explained, predictions of employment impacts should be regarded with caution. Available data only permit insights into the likely directions for employment change.

This chapter examines how PA is likely to affect employment opportunities, drawing on inferences from case studies, site visits, interviews, and technical literature. It focuses on change at the level of the firm and the industry. The first section describes how, and why, programmable automation will shape job opportunities. It traces potential effects on tasks and skills. The second section describes where employment impacts are likely to be experienced, by industry and by geographic region. The third section explores the implications of programmable automation for specific occupational groups. Together, the first three sections identify the groups of people most likely to experience employment change and the types of change they may confront.

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[3] Wassily Leontief and Faye Duchin, *The Impacts of Automation on Employment, 1963-2000*, final report, New York University, Institute for Economic Analysis, April 1984.

[4] Ibid.

The final sections address the implications of those changes for the labor market overall. The fourth section discusses the overall effect of likely impacts on tasks, skills, and occupations. It draws on other studies of individual automation technologies and industries to provide perspective. The fifth section discusses contextual factors that will shape observed employment patterns. It identifies trends in the supply of labor, and it describes recent Japanese experiences in adjusting to automation.

Effects of Programmable Automation on Jobs

As figure 14 illustrates, change in employment induced by new technology depends on how technology alters the tasks to be done in manufacturing jobs, on what changes occur in the skills required for different tasks and jobs, and on how the roles of different occupations change; total employment change also depends on changes in how labor is used within and between industries and changes in labor supply. The effects of PA on work opportunities are so varied and (at times) so profound that they call into question the basic definition of "skill," the identification of where skill fits into the production process, and the relationships between tasks, skills, occupations, and jobs. Changes in task assignments and skill requirements vitiate traditional occupational descriptions, which form the basis of occupational employment forecasting.*

Employers create jobs by combining sets of tasks and allocating them to individuals. Jobs with similar descriptions and avenues of preparation are classified as occupations. Indeed, the design of training programs depends on the expectation that people in designated occupations or jobs will perform specific tasks. Unfortunately for the analyst, what is actually done on the job frequently differs from the formal job description. Differences in actual function between various jobs and occupations are often nominal, while companies differ in what they ask of people in the same occupations, even within a given industry.

Computer-based technologies, including numerical control (NC) technology, have already led to different staffing patterns within and among countries, varying on the basis of industrial traditions, labor market conditions, prevailing types of company structure, and national educational systems. These variations further complicate employment forecasting, as employment change depends on a series of decisions yet to be made by current and potential employees, employers, and educators.

A German analysis of flexible manufacturing systems (FMS), for example, concluded that work within an FMS was comprised of a set of tasks that could be allocated in numerous ways generally not bound by the technology (see table 16). The authors illustrated this point by contrasting two cases, one with three types of jobs directly associated with the FMS, the other with five. They concluded that, while the technology permits unusual freedom in defining jobs, and is particularly conducive to multifaceted jobs, radical change in job de-

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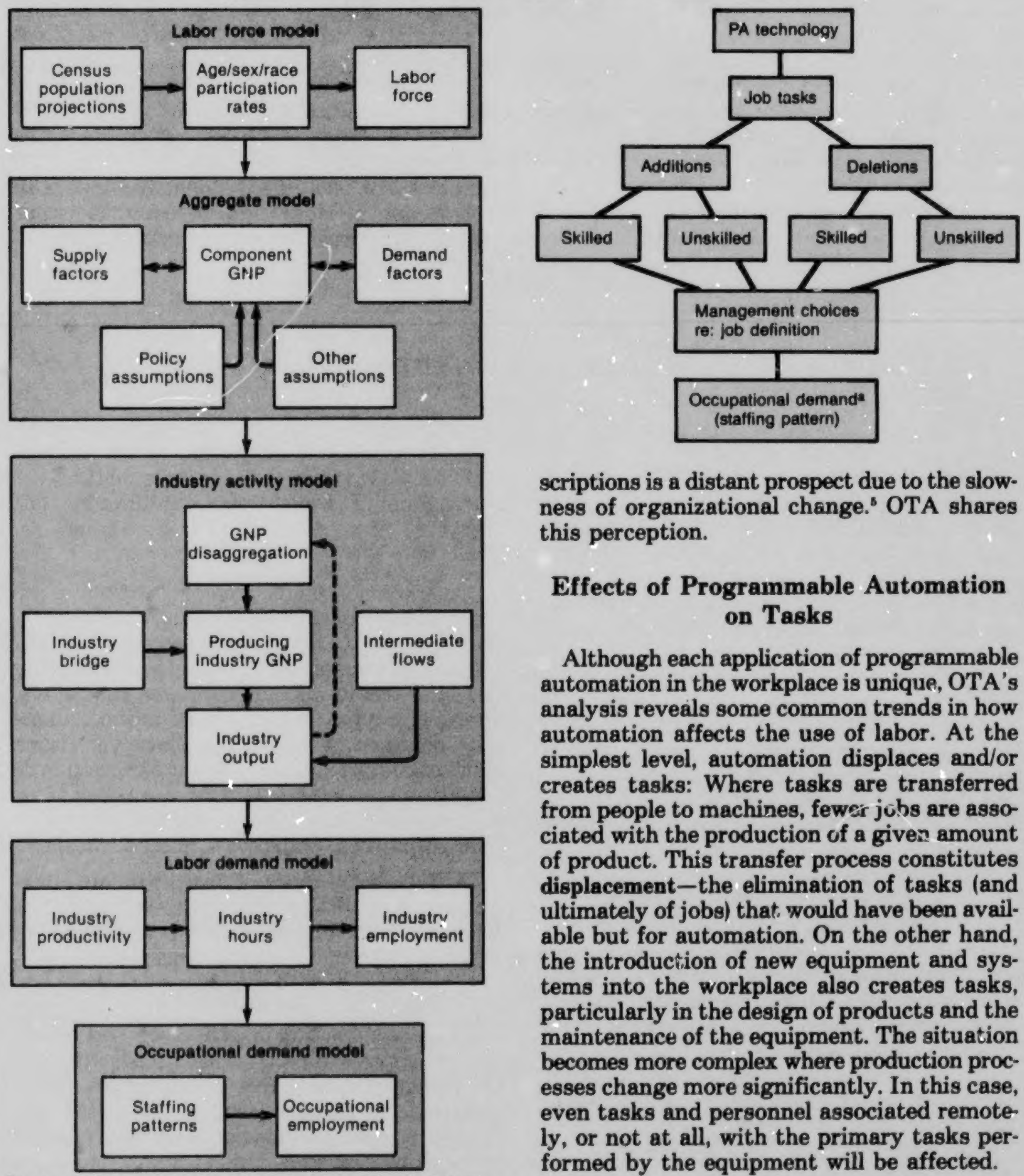
*The changes may occur only informally, at least at first, and may not be reflected in job titles.

Figure 14.—Conceptual Model: Occupational Demand Change


Labor force model
Census population projections
Age/sex/race participation rates
Labor force
Aggregate model
Supply factors
Component GNP
Demand factors
Policy assumptions
Other assumptions
Industry activity model
GNP disaggregation
Industry bridge
Producing industry GNP
Intermediate flows
Industry output
Labor demand model
Industry productivity
Industry hours
Industry employment
Occupational demand model
Staffing patterns
Occupational employment
PA technology
Job tasks
Additions
Deletions
Skilled
Unskilled
Skilled
Unskilled
Management choices re: job definition
Occupational demand[a] (staffing pattern)

[a]Employment levels will depend on industry and labor supply factors, as well as levels of economic activity, as noted in larger model above.

SOURCE: Office of Technology Assessment, with input from Robert Bednarzik of the U.S. Department of Labor; Bureau of Labor Statistics.

scriptions is a distant prospect due to the slowness of organizational change.[5] OTA shares this perception.

Effects of Programmable Automation on Tasks

Although each application of programmable automation in the workplace is unique, OTA's analysis reveals some common trends in how automation affects the use of labor. At the simplest level, automation displaces and/or creates tasks: Where tasks are transferred from people to machines, fewer jobs are associated with the production of a given amount of product. This transfer process constitutes **displacement**—the elimination of tasks (and ultimately of jobs) that would have been available but for automation. On the other hand, the introduction of new equipment and systems into the workplace also creates tasks, particularly in the design of products and the maintenance of the equipment. The situation becomes more complex where production processes change more significantly. In this case, even tasks and personnel associated remotely, or not at all, with the primary tasks performed by the equipment will be affected.

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[5] Werner Dostal, et al., "Flexible Manufacturing Systems and Job Structures" (Mitteilungen aus der Arbeitsmarkt- und Berufsforschung), 1982.

Table 16.—Basic Tasks: Activity Elements With NC Machines and Flexible Manufacturing Systems

Programing and planning:
  1. preparation of a program
  2. modification of a program
  3. preparation of tool blueprint
  4. preparation of mounting blueprint
  5. processing problems: interviews for additional information
  6. the activities of a programer or operator in case of breakdowns

Preparation and equipment:
  1. making the tools available and transportation of tools and mounting means
  2. presetting of tools and mounting means
  3. control of tool installation; bringing of tools into play
  4. preparation and setting up of mounting means and devices
  5. lifting and putting down of a workpiece
  6. mounting of workpieces according to the mounting blueprint and one's experience
  7. control of mounted workpieces
  8. switching on and adjustment of refrigerant afflux

Preparing and equipping:
  1. input output media insertion, spooling removal
  2. zero adjustment
  3. placing the correction switch according to tool and mounting blueprint
  4. placing correction switch towards tool lock
  5. test run with coordinate and cutting direction control

Operation and supervision of machines:
  1. starting of a program run
  2. observing of the operating cycle
  3. removal of shavings
  4. changing of tools and mounting
  5. supervision of the operating status of the installation
  6. discovery of false control movements
  7. activating of the switch in case of breakdowns
  8. removal of breakdowns

Controlling and monitoring:
  1. measure and surface control during processing
  2. control of the complete workpieces
  3. installation care
  4. putting into operation and keeping in operation
  5. training of an operator

SOURCE: W. Dostal, et al., "Flexible Manufacturing Systems and Job Structures" (Mitteilungen aus der Arbeitsmarkt- und Berufsforschung), 1982.

Task Displacement

Automated equipment and systems perform specific, primary tasks previously or otherwise done by people, such as welding, materials handling, and revision of product designs. The fewer the tasks in the original job definition, the more likely that automation of a given task will lead to job displacement. For example, if a person does only spot welding, the introduction of a spot-welding robot is more likely to result in the elimination of part or all of that job than if the person did spot welding and other tasks, such as welding-gun repair.

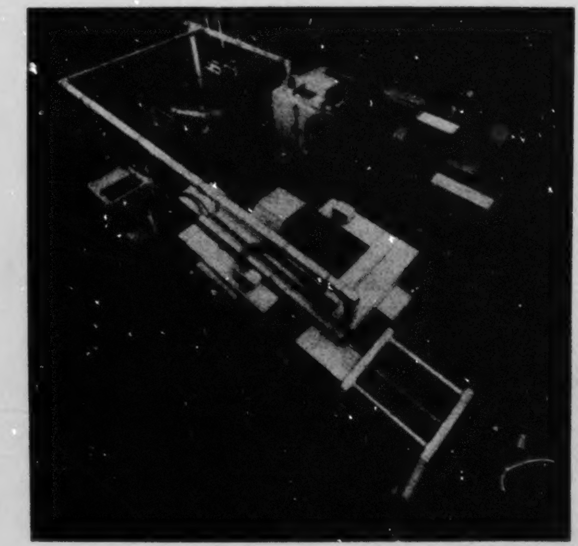

Photo credit: Cincinnati Milacron, Inc.

Machine cell with two computerized numerically controlled turning centers and robot for machine loading/unloading and inspection

Programmable equipment and systems can substitute for labor more readily than can conventional equipment, in part because of their versatility; a single system can perform multiple tasks. In particular, they perform secondary tasks in the factory, such as collecting and transferring information on equipment use or movement of parts, and even automating the flow of materials. Consequently, programmable automation may assume tasks traditionally done by nonproduction labor, from managers to stock-chasers, as well as those done by production workers. Also, substitution for labor may occur when PA is used to replace other types of equipment. For example, robots have been adopted by automobile manufacturers as an alternative to automatic welding machines (run by people) to do spot welding in automotive assembly.

The possibilities for displacing labor are generally greater for computer-integrated manufacturing (CIM) systems than for stand-alone applications of automation, although such systems do not eliminate all need for human input. For example, a single arc-welding robot may require an operator (although that robot/person combination may make the hiring of additional welders unnecessary if it is more productive than a single human welder). On the other hand, a single materials-handling robot serving other pieces of equipment may displace a human materials-handler without requiring an operator, although at least one person may oversee the larger assemblage of equipment. Similarly, flexible manufacturing systems have the potential to displace more people for a given set of machining tasks than do stand-alone NC machine tools. However, because the art of designing and implementing successful integrated manufacturing systems remains immature, and because FMS implementation is (and is expected to remain) limited, significant labor displacement by either CIM or FMS is unlikely in the near term.*

Programmable automation does not always substitute for labor in an obvious or direct way. For example, early research into bin-picking robot applications showed that it was more efficient to do away with human-like sequences of steps than to imitate them.[6] In some cases, automation accompanies or motivates major changes in production processes which themselves alter the use of labor. As a sequence of production operations, a process determines the types and amount of tasks humans or machines can perform. For example, computer-aided design (CAD) (in its higher forms) allows many product designs and production plans to be tested through simulations rather than through the building and manipulation of prototypes. Accordingly, an aircraft manufacturer developed a CAD package for rationalizing piping design, replacing its prior practice of building full-scale mockups of pipe layouts against which production piping was then matched.[7] These two practices, prototype and simulation, have vastly different implications for staffing: in simple terms, prototype construction involved production labor, especially skilled workers, while simulation and computer analysis involve engineers and technicians.

Other cases of process change are even more dramatic. For example, when IBM installed a robot to test pin placement for component wiring, the robotic application essentially eliminated the practice of delayed testing of completed assemblies by people using diagnostic software packages. (This robotic application may in turn be replaced by a process for chemically bonding wires to boards, eliminating the need for pins.) As these examples suggest, even stand-alone applications of programmable automation can give rise to radical manufacturing process changes. The more extensive the process change, the more obscure the direct implications for jobs even though the potential impact may be substantially greater.

Process change, with or without automation, often is accompanied or occasioned by a change in product design.* This combination

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*James Bright drew the same conclusion about the displacement potential of systems by evaluating conventional automation and the use of computers in the late 1950's and early 1960's. In a paper prepared for the U.S. National Commission on Technology, Automation, and Economic Progress in 1966, Bright noted that the degree of mechanization varies among applications along three dimensions: 1) "span," or use across a sequence of operations; 2) "level," the degree of automatic process control; and 3) "penetration," the extent to which such secondary and tertiary tasks as setup and repair are automated. Bright concluded that "successive advances in automatic capability generally reduce operator duties and hence contributions" (p. II-210). He observed that sophisticated systems can and will automate conceptual as well as physical work. In contrast, simpler systems tend more to function as tools, complementing the human user. See James R. Bright, "The Relationship of Increasing Automation and Skill Requirements," *The Employment Impact of Technological Change*, app. vol. II to the report of the U.S. National Commission on Technology, Automation, and Economic Progress (Washington, D.C.: U.S. Government Printing Office, February 1966).

[6] Steven Ashley, "GE to Install Forging Bin Picker Robot," *American Metal Market/Metalworking News*, June 6, 1983.

[7] OTA case study.

*For example, continuing reductions in computer size reduce the number of parts used in computers, resulting in fewer fabrication and assembly tasks. Also, companies seeking to design products for ease of production are increasingly designing products that can be assembled like "layer cakes," built from the bottom up in layers with no need for upending during assembly. Such design changes reduce production labor with or without automation.

of events generally complicates the analysis of displacement. Most employment forecasts assume constant product characteristics, which imply constant (average) requirements for labor, capital, and materials. The more variables that change, the harder it is to model production and forecast related employment. Furthermore, conventional employment forecasting techniques are ill-suited to evaluate simultaneous changes in product and process characteristics because these potentially involve changes in industry characteristics, such as production scale, number of firms, and number and nature of suppliers.

Task Creation

Although process change may vary in degree, it is the principal reason that programmable automation can also be said to **create** jobs. Tasks (and thus jobs) are created through technology change in several ways: first, the use of programmable automation may entail more intensive work in some areas. For example, automated systems tend to require more maintenance work than conventional and stand-alone equipment, in part because the cost of a breakdown is much higher. Similarly, CAD and CAE (computer-aided engineering applications of CAD) may stimulate design and engineering activity. As those technologies have made design and product engineering easier and cheaper, employers have hired more engineers.

Second, the introduction of software and integrated databases associated with programmable automation creates a need for new types of support work, such as database management, software maintenance, and programing. Taking the long view, however, some support tasks may only be needed temporarily: The integration of different types of equipment eliminates some of the programing work associated with separate units. This phenomenon is discussed further in a later section of this chapter (see "Transient Skill Requirements").

Third, if buyers want a given product, programmable automation may help producers sell enough to maintain or even increase employment. For example, several small metalworking firms studied by OTA increased their business (and employment) by using NC machinery, which helped them to deliver more quickly and develop better bids.[8] Change in employment levels depends most heavily on the level of demand for different products, which depends in turn on consumer preferences and budgets.

Fourth, the production, distribution, and servicing of programmable automation will also generate tasks and jobs. Since automated equipment sometimes replaces conventional equipment, the net increase in work depends on how much employment falls among producers of conventional equipment. For example, companies may buy robots as an alternative to nonprogrammable materials-handling equipment. The employment potential within the PA-producing industries is discussed in a later section.

Other Task Effects

Programmable automation is also used for tasks people are not well-suited for or likely to do, because the tasks would be too difficult, risky, and/or time-consuming, and consequently too expensive.* One example is the design of integrated circuits, for which computer assistance is considered necessary (although conceivably teams of people at drawing boards could eventually do what individuals at terminals do much more quickly). Similarly, for certain types of complex machining (e.g., for ships' propellers), NC is considered necessary or preferable. In both cases, the equipment is not totally automatic; human input is required. At this time, programmable automation appears essential for only a relatively few tasks. That set may be enlarged as manufacturers refine and take advantage of PA's capabilities and as totally new products are invented. The inability to forecast such new products again interferes with employment forecasting.

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[8] OTA case study.

*The application of PA to hazardous and unpleasant tasks is discussed in ch. 5, "Work Environment." One example, though, is Chrysler's decision to use a robot to paint the inside of a minivan. According to the vice president for manufacturing, "It replaces only one guy, so costwise, it will never pay off. But painting the inside of a van is the most miserable job in the plant." See John Holusha, "Chrysler: New Van and Plant," *The New York Times*, Oct. 28, 1983.

Effects of Programmable Automation on Skills

Programmable automation, through its effects on the tasks performed in manufacturing firms, also affects the types of job skills required for those tasks. In some cases, the creation of new tasks and the elimination of old ones clearly raises or lowers skill requirements. Often, however, the effect on skill demand is ambiguous, because the skills associated with individual jobs and the average skill level of a company's jobs depend on how work is allocated among individuals. Skill demand also depends on how well employers understand what skills they really need. By altering the balance of work between people and machines, PA makes it possible for managers to reallocate work in ways that either raise or lower the skill requirements of jobs.

OTA's appraisal of the effects of PA on the workplace suggests that these technologies will alter both the "depth" and "breadth" of skill requirements. Skill depth refers to the input needed to perform an individual task or group of interconnected tasks, while skill breadth refers to the input needed to perform a set of (nonsimilar) tasks. For example, a journeyman machinist (who sets up and operates machine tools, applying a knowledge of mechanics, mathematics, metallurgy, layout, and machining[9]) has skill **depth** in the area of machining. Traditionally, subjective notions about which people do skilled work—e.g., craftsmen, professionals, specialists—draw on the concept of skill depth. Skill **breadth** has traditionally been viewed with more ambivalence—e.g., "jack of all trades and master of none." This is one reason why labor contracts in unionized firms, for example, contain job classifications that define relatively narrowly the requirements and tasks of specific jobs. It is these qualities that govern people's perceptions about whether skill requirements have risen or fallen.

Skill Depth

Skill depth has two dimensions: time to proficiency, and judgment. Jobs comprised of tasks that require little or no time to master (e.g., food service or filing) and limited judgment tend to be low-skilled jobs in which access is broad and pay is relatively low. The longer the time to proficiency, the more likely that formal training is required for hiring and promotion. For example, conventional drafting requires at least 2 years of technical training, while electrical engineering requires at least 4 years of formal training. Although salaried (so-called "white collar") and hourly ("blue collar") work traditionally offer different, usually quite separate, career paths, both types of work include hierarchies of jobs that differ in terms of time to proficiency and judgment, as well as other traits.

Programmable automation seems to lower the time to proficiency and judgment required for many tasks, including those performed by professionals as well as craftworkers. Thus, it tends to reduce the need for skill depth in related jobs. Through computerization (and accompanying aspects of mechanical design), automated equipment offers the ability to perform a variety of relatively easy-to-learn tasks (e.g., drawing basic shapes) and increasing numbers of more sophisticated tasks (e.g., process planning). With PA relevant information is, in effect, shared between operators and equipment. People working with automated systems therefore have fewer decisions to make, while those who control the design of a system have more.

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[9] U.S. Department of Labor, Employment and Training Administration, *Dictionary of Occupational Titles*, 4th ed. (Washington, D.C.: U.S. Government Printing Office, 1977).

Thus, reduction in skill depth is largely due to a shift in emphasis away from complex manual work and toward simpler mental work, but it may involve decreases in both manual and mental tasks. For example, a study comparing early NC machine tools to conventional equipment noted that physical effort was diminished (in an amount depending on the extent of "automation"), demand for motor skills "and the associated perceptual load related to precision and accuracy of movement" were reduced, and the number of operator decisions fell.*

Computerization may affect skill requirements by allowing greater freedom in the allocation of tasks. For example, NC technology allows programing to be separated from machine operation; CNC (computerized numerical control), however, facilitates the combination of programing and operation into a single job. If NC programing is performed by a separate programer, less judgment and proficiency is required for machine operation. As another example, CAD systems are being developed that prevent certain actions, including mistakes.** On the other hand, CAD itself may allow engineers to complete designs without the aid of draftsmen.

Since there is less to learn to operate CAD or NC equipment, people with initially lower skills can produce better, faster than they could with conventional technology. Recognizing this, many companies have separated machine operation from NC programing in order to hire less-skilled machine operators instead of high-skilled machinists. However, this is less likely to occur where the product is extremely complex and/or the work less easily shared. OTA's studies of machine shops at both small and large firms show that employers prefer skilled machinists to operate NC machines for complex tasks. It is not clear that further refinement of NC technology will eliminate this need, although it may reduce it. Consequently, it is dangerous to generalize about the impact of PA on skill requirements and staffing.

The removal of skill and the fragmentation of work have always occurred with mechanization. What makes programmable automation different from dedicated, or "hard," automation is the ability to reduce the skill required for specific tasks at higher levels in the organization (see discussions of aircraft company case study in ch. 5).

Skill Breadth

The potential effects of PA on skill breadth, which applies more to jobs or occupations than to single tasks, are less evident than the effects on skill depth. Requirements for the variety of skills in a job are determined by employers, who define specific jobs and hierarchies. PA and other technologies do not force specific forms of work organization; they provide employers with sets of choices about job design and division of labor.

OTA's case studies and other sources suggest that, in some cases, personnel working with PA may require less intimate knowledge of a single process or task but also a general

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*While "conceptual skill associated with the interpretation of symbolic information in the form of drawings, planning instructions and calculations" rose, in more modern NC applications these tasks are often done by the programer rather than the operator. R. J. Hazlehurst, et al. "A Comparison of the Skills of Machinists on Numerically-Controlled and Conventional Machines," *Occupational Psychology*, vol. 43, Nos. 3&4, 1969.

**At least one commercially available system (Computervision's CADDS 4) prevents design detailers from permanently changing designs.

knowledge of more tasks. Among the cases examined by OTA, skill breadth was most required for repair and maintenance personnel. These personnel have been confronted with more varied types of equipment on the job, and with equipment that combines electrical, electronic, and mechanical features. Also, programmable automation calls more attention to production processes, to the linkage (with and without computer-based integration) of activities into systems and of system to system. Consequently, some experts argue that professional, technical, and managerial staff, in particular, require broader familiarity with production activities and their interconnections (as well as an understanding of the means and limitations of computer control).

Skill breadth may be associated with changing job content. A Japanese survey of electrical machinery workers reported that most of these workers found that microelectronics was associated with frequent change in the content of their work.[10] Elsewhere, Japanese researchers concluded from a series of automation case studies that changes in jobs and job content erode the value of experience; one reported solution was to promote experienced workers to various tasks involving watching over equipment.[11]

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[10] Denki Roren, "Surveys on the Impacts of Micro-Electronics and Our Policies Towards Technological Innovation," paper presented at the 4th IMF World Conference for the Electrical and Electronics Industries, Oct. 3-5, 1983.

[11] Japan Labor Association, "A Special Study Concerning Technological Innovation and Labor-Management Relations," interim report, June 1983.

Effects of Programmable Automation Employment By User Industry

Which people will face changing job opportunities depends on which industries are likely to use programmable automation, when, where, and how, as well as on the capabilities of the technologies. Given the range of potential applications described in chapter 3, it is possible to identify the industries as well as the occupational groups likely to be affected. Indeed, because of its flexibility (and other attributes), PA can be used in a remarkably broad range of industries. In this regard, it is but one manifestation of the growing use of computer technologies taking place throughout the economy. This section will discuss PA users; the employment potential of PA producers (who also tend to be users) is discussed later in the chapter.

The first and principal users of the technologies addressed in this report have been firms in the so-called metalworking industries—primary metals, fabricated metal products, electrical machinery (includes electronics), nonelectrical machinery, transportation equipment, and instruments[12]—particularly the electrical and nonelectrical machinery and transportation equipment industries.[13] Together these industries employed almost 10 million people in 1980; the electrical and nonelectrical machinery and transportation equipment industries employed almost 8 million. Their occupational profiles are shown in table 17. Other industries, including architectural and engineering services, have also begun to be significant users of programmable automation; engineer-

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[12] Industries designated by Standard Industrial Classification (SIC) codes 33-38.

[13] Ibid. (SIC 35-37).

Table 17.—Occupational Profiles of Manufacturing Industries

Employment in Manufacturing Industries by Major Occupational Group, 1980

Industry	All occupations	Managers and officers	Professional workers	Technical workers	Service workers	Production, maintenance, construction, repair, material handling, and powerplant workers	Clerical workers	Sales workers
All manufacturing	100.0	6.6	6.9	2.9	1.8	68.1	11.5	2.2
Food and kindred products	100.0	6.4	2.7	.7	3.1	73.2	10.0	3.9
Tobacco products	100.0	5.9	3.7	1.9	3.5	72.8	10.9	1.2
Textile mill products	100.0	3.7	1.7	.9	2.2	81.9	8.8	.8
Apparel and other textile products	100.0	3.6	1.2	.2	1.2	83.2	9.1	1.4
Lumber and wood products, except furniture	100.0	6.2	1.5	.8	2.1	81.4	6.4	1.7
Furniture and fixtures	100.0	5.3	2.2	.8	1.9	76.4	11.1	2.3
Paper and allied products	100.0	5.3	4.3	1.5	1.7	74.3	10.5	2.4
Printing and publishing	100.0	10.1	9.9	1.0	1.7	48.6	21.1	7.4
Chemicals and allied products	100.0	9.8	12.3	5.3	2.2	52.6	14.6	3.2
Petroleum refining and related industries	100.0	7.3	9.4	3.1	1.5	62.8	11.4	4.5
Rubber and miscellaneous plastics products	100.0	6.5	4.1	1.7	1.6	75.1	9.5	1.5
Leather and leather products	100.0	3.9	1.4	.3	1.3	80.6	10.4	2.0
Stone, clay, glass, and concrete products	100.0	7.3	3.1	1.4	1.4	75.6	9.0	2.0
Primary metal products	100.0	3.9	3.8	1.9	2.0	79.4	8.2	.9
Fabricated metal products	100.0	6.6	4.2	2.1	1.6	73.7	9.8	1.9
Machinery, except electrical and transportation equipment	100.0	7.8	9.4	5.4	1.8	60.7	13.3	1.8
Electrical and electronic machinery	100.0	6.4	12.3	6.2	1.4	60.3	12.3	1.0
Transportation equipment	100.0	5.8	13.1	3.9	2.2	64.7	9.7	.5
Instruments and related products	100.0	8.7	11.6	7.4	1.7	53.7	14.9	1.9
Miscellaneous manufacturing industries	100.0	7.7	3.5	1.5	1.7	68.8	14.1	2.6

Percent Distribution of Employment in Manufacturing Industries by Major Occupational Group, 1980

Industry	Managers and officers	Professional workers	Technical workers	Service workers	Production, maintenance, construction, repair, material handling, and powerplant workers	Clerical workers	Sales workers
All manufacturing	1,328,160	1,404,080	594,270	373,150	13,767,040	2,322,400	438,710
Food and kindred products	107,750	45,360	12,000	52,000	1,241,080	169,730	66,910
Tobacco products	3,780	2,380	1,220	2,230	46,270	6,960	760
Textile mill products	31,980	14,710	7,750	19,110	713,410	76,780	7,040
Apparel and other textile products	45,820	15,500	2,250	15,290	1,057,890	116,190	18,420
Lumber and wood products, except furniture	41,070	9,890	5,090	13,520	534,720	41,920	11,060
Furniture and fixtures	24,300	10,200	3,610	8,510	348,250	50,490	10,470
Paper and allied products	37,340	30,190	10,500	11,570	519,530	73,240	16,540
Printing and publishing	126,830	124,270	12,620	20,980	612,420	284,290	92,890
Chemicals and allied products	110,000	137,650	58,990	24,700	587,520	162,670	35,290
Petroleum refining and related industries	14,790	19,030	6,290	3,080	127,290	23,040	9,170
Rubber and miscellaneous plastics products	45,860	28,880	12,190	11,420	534,150	67,470	11,020
Leather and leather products	9,130	3,390	720	3,030	190,440	24,640	4,840
Stone, clay, glass, and concrete products	48,720	20,930	9,580	9,520	503,440	60,130	13,310
Primary metal products	47,550	46,350	22,320	23,540	956,430	98,230	10,680
Fabricated metal products	103,670	67,110	33,650	25,750	1,164,180	154,800	30,800
Machinery, except electrical and transportation equipment	195,830	234,740	134,550	39,900	1,515,840	332,490	44,140
Electrical and electronic machinery	133,520	255,880	129,720	29,310	1,254,920	255,900	20,390
Transportation equipment	106,320	240,400	72,110	40,480	1,188,110	178,180	9,470
Instruments and related products	61,500	82,460	52,840	12,130	361,320	105,970	13,540
Miscellaneous manufacturing industries	32,400	14,760	6,270	7,080	290,030	59,280	11,970

SOURCE: Bureau of Labor Statistics, *Occupational Employment in Manufacturing Industries*, Bulletin 2133, September 1982.

ing and architectural services employed 557,000 people in 1980.[14]

Application of the PA technologies will grow relatively quickly among these early users. Their experience will facilitate further application of PA, including the integration of systems. For example, GM's widely publicized plan to have over 14,000 robots by 1990 reflects not only the firm's size, but also its experience with robots and its understanding of how and where to use them. Because use of automated production technologies, in particular, will probably remain concentrated in these industries through this decade, principal near-term employment impacts will also be concentrated in these industries.

Programmable automation will be applied in a growing variety of industries because of improving capabilities, falling costs, and growing experience with particular applications, as well as the perceived effect on competitiveness. Materials handling, assembly, simulation, and inventory control applications can be used across the manufacturing sector; this contrasts with the more narrow market for robotic spot welding and spray painting, NC machining, and CAD for electronic equipment. Already, industries such as food processing, textiles, apparel, and paper manufacturing have begun to explore use of programmable automation, especially robots. Applications of these technologies will spread both within the manufacturing sector and outside of it, but sufficiently slowly that significant effects on employment outside of the metalworking industries are unlikely before 1990.

Some perspective on the unevenness of technology diffusion, and its impact on employment by industry, can be gained from data on the spread of NC technology. In 1968, only 0.5 percent of machine tools in use among metalworking industries in general were numerically controlled. The percentage was only slightly higher for nonelectrical machinery industries. In the 1976 to 1978 period, the overall figure was 2.0 percent, varying among industries from 0.3 percent for metal stampings to 5.3 percent for aircraft and parts. The overall figure was 4.7 percent by 1983. These figures underscore the fact that production technologies tend to spread slowly and unevenly. Within the machine-tool industry itself, the proportion of NC machine tools was 2.6 percent in 1973, 3.7 percent in 1976-78, and 6 percent in 1983.[15]

Firm size may affect the incidence of employment impacts within and across industries. To date, most users of PA, especially the production technologies, have been large firms. Such firms may continue to dominate as users because they can more easily purchase equipment, buy or build on previous know-how, and otherwise afford to automate.[16] Industries dominated by large firms may therefore experience faster employment change than industries dominated by smaller firms, other things being equal; the changes will come in larger doses. On the other hand, larger firms generally have more capacity to transfer and retrain displaced personnel, making layoffs less likely. Also, supplier-buyer links between large and smaller firms may hasten the adoption of programmable automation by smaller firms.* The domination of the aerospace and auto industries by a few large firms linked to a number of smaller suppliers can heighten the employment impacts within those industries.*

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[14] Bureau of Labor Statistics, "Employment by Industry and Occupation, 1982 and Selected 1995 Alternatives," unpublished data on wage and salary employment, 1983.

[15] "The 13th American Machinist Inventory of Metalworking Equipment 1983," *American Machinist*, November 1983; and National Machine Tool Builders' Association, *1983-84 Handbook of the Machine Tool Industry*.

[16] Steven M. Miller, *Potential Impacts of Robotics on Manufacturing Costs Within the Metalworking Industries*, doctoral dissertation, Carnegie-Mellon University, 1983.

*So, too, will improvement of low cost systems aimed at smaller users.

Geographic Incidence

Programmable automation will exacerbate employment problems in certain geographic areas in the short term (i.e., the 1980's). In the longer term, however, its impacts will be more general.

Given the differing tendencies of different industries to use programmable automation, employment in the East North Central and Middle Atlantic regions, plus individual States such as California and Texas, are most likely to be affected during this decade, as well as the next. Employment in such metalworking industries as automobiles and nonelectrical machinery is concentrated in the East North Central region, especially in Ohio, Michigan, and Illinois; the Middle Atlantic region is a major source of industrial machinery; California and Texas are major sources of electrical machinery and aerospace products. See figure 15 for a comparison of regional differences in manufacturing employment. These areas include the six States that had 5 percent or more of their employment in manufacturing and together held over 42 percent of all manufacturing employees, according to the 1977 Census of Manufacturers (latest version available)—California (9 percent), New York (8 percent), Pennsylvania (7 percent), Ohio (7 percent), Illinois (7 percent), and Michigan (6 percent).

In the short term, areas most dependent on single firms or industries will be the most vulnerable to the effects of employment change. As the authors of an OECD study of job losses in major industries across countries noted, "the proportion of the community's workers involved in the primary cutbacks" is the principal determinant of the effect of displacement and unemployment on a community.[17] This proportion, and a related factor, the diversity of the local economy, both affect the ability of the local labor market to absorb displaced workers. Such vulnerability, however, exists independently of PA or any other technology; lack of economic diversity has long been known to make local economies vulnerable to any changes in hiring by dominant employers. As table 18 shows, States with a lot of manufacturing were likely to have experienced above-average unemployment over the past 7 years, although other States also experienced high unemployment.

The East North Central region is particularly likely to experience unemployment because of its association with the auto industry. That industry is not only a major user of programmable automation, but is also particularly sensitive to import competition and to changing consumer car-buying behavior. Consequently, even before the auto industry's use of robots was attracting much publicity, there was speculation that industry employment might not re-attain the peak levels achieved in 1978 and 1979. The same area is also experiencing job losses associated with other industries, such as the industrial, farm, and construction machinery industries. These industries are not only automating but have also been contracting due to import competition and the cyclical declines in business.

Increasingly, the employment impacts of programmable automation will become dispersed because of the broadening geographic distribution of manufacturing activity. Over

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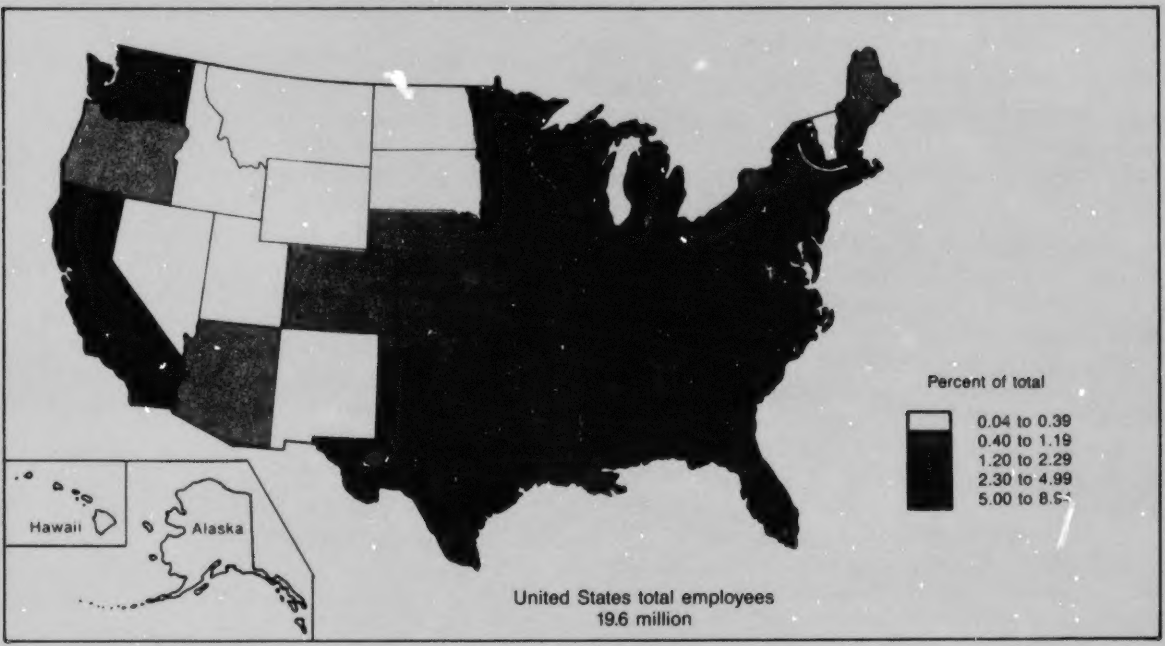
*On the other hand, the movement among major metalworking firms toward using fewer suppliers (to improve quality control) may shift supply business toward larger firms, which may have a greater propensity to automate. The extent of this movement varies among industries. It is especially pronounced in the auto industry, for example. See Nancy Kingman, "OEMs Plan to Utilize Fewer Supplier Firms," *American Metal Market/Metalworking News*, Oct. 10, 1983.

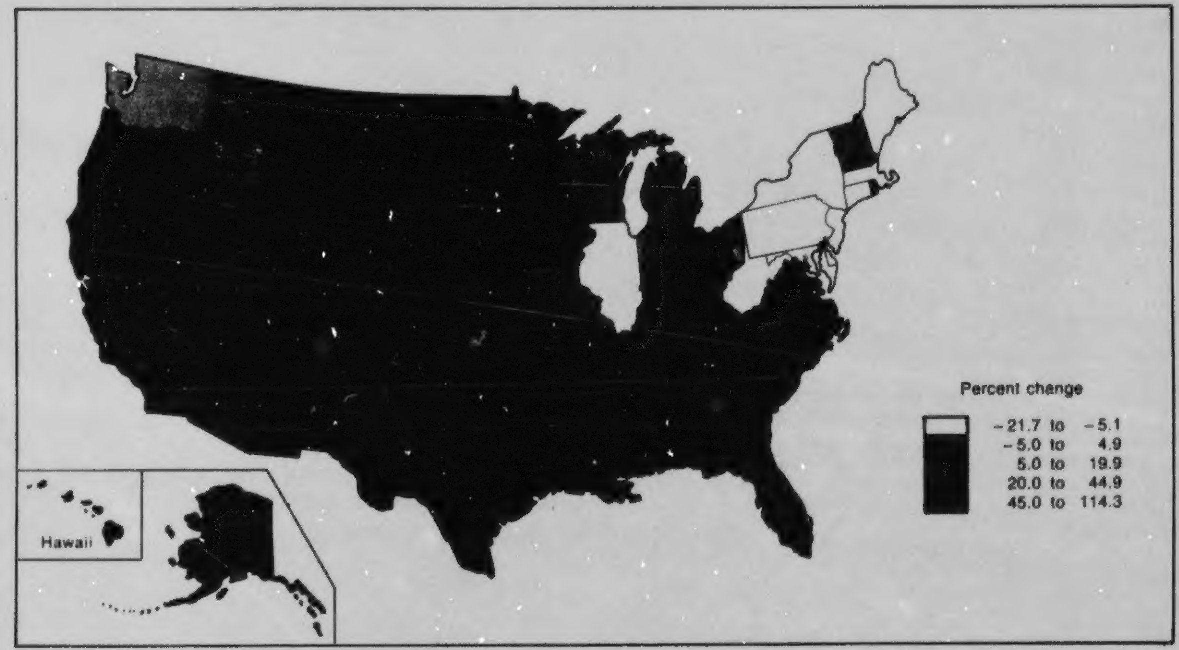
[17] Robert B. McKersie and Werner Sengenberger, *Job Losses in Major Industries* (Paris: OECD, 1983).

Figure 15.—Regional Manufacturing Employment

Employment as a percent of U.S. total, by State: 1977


Hawaii
Alaska
Percent of total
0.04 to 0.39
0.40 to 1.19
1.20 to 2.29
2.30 to 4.99
5.00 to 8.5
United States total employees
19.6 million

Change in employment, by State: 1967–77


Hawaii
Percent change
-21.7 to -5.1
-5.0 to 4.9
5.0 to 19.9
20.0 to 44.9
45.0 to 114.3

SOURCE: U.S. Department of Commerce, Bureau of the Census.

Table 18.—Unemployment Rates by State,[a] 1976-82

	1976	1977	1978	1979	1980	1981	1982
Annual average rate (%)	7.2	6.7	5.7	5.6	6.9	7.3	9.3

Distribution of State unemployment relative to average

Number of years above average	Number of States	Identity of States
0	14	Colorado, Iowa, Kansas, Minnesota, Nebraska, New Hampshire, North Carolina, North Dakota, Oklahoma, South Dakota, Texas, Utah, Virginia, Wyoming
1	2	Maryland, Montana
2	4	Connecticut, Georgia, Missouri, Vermont
3	5	Kentucky, Massachusetts, Nevada, South Carolina, Wisconsin
4	6	Arizona, Florida, Hawaii, Idaho, Illinois, Indiana
5	7	Arkansas, Louisiana, Maine, New Jersey, New Mexico, Ohio, Tennessee
6	4	California, Delaware, Mississippi, New York
7	9	Alabama, Alaska, District of Columbia, Michigan, Oregon, Pennsylvania, Rhode Island, Washington, West Virginia
	51	

[a] Including the District of Columbia.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey.

the last two or three decades, manufacturing has grown in the South and in the Western regions of the country, aided in part by government spending. Between 1960 and 1970, the number of manufacturing employees in the Northeast was almost constant, while in all other regions it grew substantially. Between 1970 and 1980, manufacturing employment fell in the Northeast, remained constant in the North Central region, and grew relatively rapidly in the South and West. By 1980, over 43 percent of manufacturing employment was in the South and West regions.[18]

The growth in manufacturing employment in the South and West reflects lower production costs in those regions compared with the Northeast and North Central, as well as a growth of the aerospace and electronics industries in California and several Southern States. These areas have benefited from space program funding in the 1960's and defense program funding since the 1950's. Between 1951 and 1976, for example, the South's share of military prime contract awards rose from 11 to 25 percent, while the West's share grew from 16 to 31 percent.[19] Defense and space R&D has, in turn, led to commercial manufacture of such associated products as calculators and semiconductors being concentrated in the same regions.

The dispersion of manufacturing does not, however, preclude regional variation in the rate and type of technology change. A recent study of geographic patterns in the use of metalworking equipment found:

> The more advanced production technologies are being introduced in the higher skill, higher wage areas of the industrial Midwest while less of these technologies or less advanced versions are being introduced to a lesser degree in the low wage, lower skill labor markets of the South and West.[20]

The authors suggest that there is a "matching of capital with labor by region," a phenomenon that will influence the geographic incidence of technological displacement and associated unemployment.

The dispersal of manufacturing activity and the growth of service industries among regions have allowed regional economies to diversify. This has made most regions less sensitive to changes in manufacturing employment.* One indicator of how widely PA use is dispersed is the distribution of service centers and demonstration facilities established by vendors. Vendor literature and the trade press suggest that such facilities are distributed quite broadly across the country.

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[18] James A. Orr, Haruo Shimada, and Atsushi Seike, "U.S.-Japan Comparative Study of Employment Adjustment," draft, U.S. Department of Labor and Japan Ministry of Labor, Nov. 9, 1982.

[19] Eileen Appelbaum, " 'High Tech' and the Structural Unemployment of the Eighties," paper presented at the American Economic Association Meeting, Washington, D.C., Dec. 28, 1981.

[20] John Rees, et al., "The Adoption of New Technology in the American Machinery Industry," Occasional Paper No. 71, Maxwell School of Citizenship and Public Affairs, Syracuse University, August 1983.

*Note, however, that encouragement of just-in-time supply systems by the auto and other industries may encourage recentralization (for the auto industry, at least, in the Midwest).

Another influence on geographic incidence is the combination of PA with advanced telecommunications systems linking facilities across a region or even across countries. For example, Lockheed has found that its use of CAD and CAM has affected its interfacility activity.

> Inter-company use of CADAM-generated data through an interactive system using satellites allows for the transmission of CADAM models between four Lockheed companies that are now on-line. Once the remaining companies have been added to the network, said [a Lockheed official], "we can design at one plant, program at another and manufacture at still another plant."[21]

Automation producers face similar prospects. For example, ASEA Robot Co. has facilities in Detroit, White Plains, New York City, Houston, and Los Angeles, and it installs robots around the country. It adopted a communications system "that will allow ASEA engineers in New Berlin (Wis.) to work directly with technicians installing equipment anywhere in the nation" through computer connections.[22] Computer and telecommunications links, together with PA systems, enable manufacturers to spread a given complement of personnel across a large geographic area and avoid fully staffing separate local facilities.

There is also an **international** dimension to geographical impacts. In particular, the availability of programmable automation may influence manufacturers' decisions about locating production in the United States or abroad. Some proponents of PA argue that a principal benefit may be to stem or reverse the exodus of manufacturing jobs to other countries. There is some evidence that the cost-reducing effect of PA has motivated companies to locate more electronics facilities in the United States than they might have previously. For example, GM-Delco recently expanded U.S. production instead of going overseas.[23] Also, AT&T attributes its plans to consolidate most of its consumer telephone manufacturing within the United States to automation, as well as to the benefits of domestic location for responsiveness to changing technologies and consumer preferences. According to an AT&T official:

> Far East, Central and South American labor rates are low . . . but we are designing and building our products for automated assembly, displacing labor with capital . . . Changes in our manufacturing operations generally represent changes in technology—moving from electromechanical phones to electronic phones. Because that technology has spread throughout the product line, and a high percentage of the value added in a product line is electronics, we are able to use automated assembly instead of the human assembly line.[24]

However, cost is not the only reason why producers choose to locate offshore. Where producers are motivated by a desire to be near a foreign market, especially if local-content laws there require local production, no reduction in costs at home will keep such production in the United States. Thus, auto and electronics producers continue to operate, expand, and buy from overseas production facilities. Digital Electronic Corp., for example, expects that half of its materials requirements will be filled by overseas sources over the next 3 to 5 years, whereas 15 percent is now.[25] If, on the other hand, programmable automation encourages more small-batch production of goods aimed exclusively at the domestic market, especially goods tailored to specific regional or ethnic preferences, then domestic manufacturing may benefit even if overseas locations remain most economical for mass production.* Insofar as multinational corporations standardize products across companies or draw on standard components, it may be harder to isolate production for the U.S. market from production for world markets. This prospect has been raised by the discussions of the "world car."** It is also becoming an issue for production of automation hardware (see ch. 7).

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[21] "Lockheed Exec: 30B Automation Market by 1990," *American Metal Market/Metalworking News*, Sept. 26, 1983.

[22] Robert Fixmer, "Swedish Robots Pick Wisconsin" (Madison), *Capital Times*, Mar. 5, 1983.

[23] John Holusha, "G.M. Electronics Back in U.S," *The New York Times*, June 20, 1983.

[24] Laurel Nelson-Rowe, "AT&T Shifting More of Its Consumer Phone Manufacturing to U.S.," *Communications Week*, Jan. 30, 1984.

[25] Nancy Kingman, "OEMs Plan to Utilize Fewer Supplier Firms," *American Metal Market/Metalworking News*, Oct. 10, 1983.

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*The time-savings benefits of computerized apparel equipment may help domestic firms compete with importers because they can deliver more quickly. "When a customer can order something and have it in his store in 2 weeks, there's no way the imports can compete," according to one clothing maker. See Fran Hesser, "Clothing Makers Try to Sew Up Labor Costs, Foreign Competition," *The Atlanta Constitution*, Sept. 21, 1983.

**Ford, for example, has a computer and communications system linking engineers in Europe and the United States for automotive design and analysis work. "Computer-Aided Engineers: Worldwide Dedicated Computers Analyze Into Structures," *Tooling and Production*, October 1983.

Effects of Programmable Automation on Occupational Employment

Occupational impacts of individual automation technologies and of accompanying major process changes will vary enormously among industries. In the absence of detailed company and industry studies of the deployment of labor across the economy, data on employment by occupation are the only means of counting people potentially exposed to the risk of displacement.* They can also be used to develop inferences about new jobs and occupations. Such estimates, it must be understood, are rough at best.

Selected Detailed Occupational Groups

Engineers

In many ways, engineers are a central factor in the employment changes expected to occur with programmable automation. Engineers develop automation technologies; they work with them; yet they are not immune to being displaced by them.

Engineers contribute to both the production and use of PA. The mix of engineers by discipline found in an enterprise varies with the nature of the product or research topic; but in general, electrical/electronic and mechanical engineers design equipment and systems, and industrial/manufacturing engineers as well as electrical and mechanical engineers design applications. Different industries have different needs for special engineering disciplines, such as aeronautical/astronautical, chemical, and metallurgical engineers. Typically, employers prefer that engineers have at least a bachelor's degree, although individuals without such training can be certified by the Society of Manufacturing Engineers to perform certain types of production engineering, and sometimes individuals attain the title of engineer through promotion from other positions. Engineers who perform research usually hold advanced degrees. The employment share of manufacturing engineers with degrees reflects the fact that employers and schools alike have historically held this engineering discipline in lower regard than others (although this view is changing, as discussed later).**

CURRENT EMPLOYMENT TRENDS

Total employment of engineers in 1980 was over 1.1 million, including about 580,000 employed in manufacturing. In 1982, nearly

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*Such data are principally available through the Bureau of Labor Statistics (BLS), although some are also available from the Bureau of the Census, the National Science Foundation, and from private sources. Most data presented in this chapter are for 1980, which represents essentially prerecession conditions and conditions prior to much of the recent growth in PA use.

**N.b., statistics collected by BLS treat manufacturing engineering as a subset of industrial engineering, although in the vernacular the term industrial engineer has a more limited meaning.

590,000 engineers were employed in manufacturing industries.

Engineers have become more prevalent in manufacturing industries over the past several years. Sectoral employment of engineers grew despite the recessions, although individual industries suffered declines in engineering employment between 1980 and 1982. Engineers comprise nearly a third of professional and technical personnel across the manufacturing sector. The electrical and nonelectrical machinery, transportation equipment, and a few other relatively technology-intensive industries (e.g., instruments and chemicals) together employ over 80 percent of the engineers working in manufacturing industries.[26] The number and distribution of engineers reflects many factors, particularly changes in process technology and patterns in defense spending (the principal factor behind employment trends for aeronautical engineers). See table 19. The relatively large growth in electrical engineering employment, for example, reflects the spread of microelectronics across various products and processes.

Technology change and other factors are causing growth in design and production engineering activity, which in turn supports growth in demand for engineers. In some cases, programmable automation is merely a vehicle for engineering activity motivated by other factors; in others, the nature of PA itself is a cause of growth in engineering. The use of CAD, for example, may be associated with increased design engineering activity because it makes design cheaper and therefore easier to do more often.* This is especially likely in industries (e.g., special semiconductors) where product differentiation and customization are increasingly important. In some industries (e.g., computers and aerospace), CAD/CAE facilitates faster advances in product technology, allowing more (and more complex) products to be introduced in a given period of time.**

Design requirements of FMS and automated storage and retrieval systems (AS/RS) are increasing producer needs for engineers. Cincinnati Milacron, for example, reports using thousands of engineering hours to analyze FMS needs of potential customers.[27] Across manufacturing generally, production engineering activities are growing because programmable automation and market factors are focusing attention on product quality, production processes, and the links between design and production. The growth of PA products and markets is itself a source (albeit limited) of increased engineering design and production activity and employment. The more complex the application of PA, and/or the greater the change in the production process, the greater the investment in engineering will be.

As was suggested earlier, the spread of programmable automation influences the mix of engineers. In particular, it is contributing (because of changes in materials technology, as well as the growing concern with manufacturing processes) to a revival of interest in the discipline of manufacturing engineering; schools report greater interest among students

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[26] "Changing Employment Patterns of Scientists, Engineers, and Technicians in Manufacturing Industries: 1977-1980," National Science Foundation, 1982.

*This would be similar to the experience with computer-based technologies for financial services, the adoption of which was associated with growth in certain banking transactions.

**According to Clarence Borgmeyer of Pratt & Whitney Aircraft, "It takes us approximately as long to design an engine as it did in 1956, but engine technology has grown infinitely more complex. We couldn't begin to solve today's problems with yesterday's computers." See "Maker of Aircraft Engines Ties Data Base to CAE Applications on Divisional Scale," *Computerworld*, Sept. 12, 1983.

[27] Lauri Giesen, "Industry Interest Sparks FMS Sales Hopes for '84," *American Metal Market/Metalworking News*, Dec. 5, 1983.

Table 19.—Number and Distribution of Engineers, 1980

	All manufacturing		Metalworking machinery and equipment		Office, computing, and accounting machines		Electrical industrial apparatus		Electronic components and accessories		Motor vehicles and equipment		Aircraft and parts	
Engineers	579,677	2.3%	11,930	3.2%	48,303	11.2%	10,602	4.5%	34,077	6.1%	17,804	2.3%	75,587	11.5%
Electrical	173,647	0.9%	1,671	0.5%	31,008	7.2%	5,818	2.4%	23,591	4.2%	466	0.1%	5,367	0.8%
Industrial	71,442	0.4%	1,963	0.5%	6,125	1.4%	1,414	0.6%	3,031	0.5%	3,921	0.5%	5,809	0.9%
Mechanical	122,328	0.6%	6,718	1.2%	3,970	0.9%	2,128	0.9%	2,769	0.5%	3,959	0.5%	11,364	1.7%

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

in pursuing a manufacturing engineering major. Also, because of their dependence on systems analysis and the need for development of computer hardware and software, PA producers and users alike appear willing and able to substitute computer scientists and systems analysts for engineers. PA is thus likely to have similar employment impacts on engineers and systems analysts because of their overlapping responsibilities, although systems analyst employment is lower overall* (see table 20).

A review of want-ads published by PA producers and users over the last 2 to 3 years shows that companies generally list engineering and computer science degrees as alternative criteria for eligibility when recruiting for both product and applications development positions. Among engineering degrees desired, electrical engineering is listed most frequently, closely followed by mechanical engineering.

Flexible hiring criteria reflect in part a growth in interdisciplinary work among engineers. Production and use of PA equipment help to spur interdisciplinary engineering because PA combines electrical, electronic, and mechanical systems technologies. In addition, design and production activities often merge with the use of PA systems, especially CAD/CAE systems that allow for analysis of production requirements and processes.

Table 20.—Employment of Computer Systems Analysts, 1980

	Number	Percent
All industries	201,999	0.20%
All manufacturing	42,404	0.20
Metalworking machinery and equipment	336	0.09
Office, computing, and accounting machines	6,913	1.60
Electrical industrial apparatus	581	0.24
Electronic components and accessories	1,146	0.20
Motor vehicles and equipment	945	0.12
Aircraft and parts	3,535	0.54

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

The rise in interdisciplinary engineering and systems analysis suggests that college training for production engineers may become increasingly necessary over time—i.e., it may become more difficult for individuals lacking college degrees to rise through the ranks and obtain engineering jobs. Confirming this assumption, 6,600 manufacturing engineers predicted in a 1979 survey that 50 percent of plant work forces in the automated environment will be engineers and technicians. Interestingly, while 49 percent of all respondents had at least a B.A., 61 percent of those between 20 and 29 years of age did.[28] However, recent want-ads suggest that, at least among today's users of programmable automation, employers may be willing to accept several years of relevant experience in lieu of a technical college degree for some engineering positions.

The growth in engineering activity caused by or accompanying programmable automation will not necessarily raise engineering employment among user firms, although it may raise it elsewhere. Many users appear to favor turnkey purchases and rely on vendors to meet occasional needs for applications engineering, rather than expand their own staffs. The Upjohn Institute, for example, found this to be the case among robot users generally.[29] Also, applications engineering services are available from growing numbers of third-party engineers employed in consulting and service firms. These engineers may substitute for in-house staff for either producers or users, performing applications engineering and planning (and sometimes contributing to product development). For example, increasing numbers of programmable controller installations are handled by third-party firms.[30]

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*In 1980, 42,404 computer systems analysts were employed in manufacturing. While manufacturing's share of computer systems analyst, operations analyst, and systems analyst employment fell overall during the 1970's, the proportions employed by metalworking industries generally rose. Between 1970 and 1978, the percent employment of computer specialists rose for all manufacturing (and for all industries combined), and in metalworking industries, while the proportions of engineers and engineering and scientific technicians fell slightly.

[28] "The Manufacturing Engineer: Past, Present and Future," special report to the membership of SME, May 28, 1979.

[29] H. Allan Hunt and Timothy L. Hunt, *Human Resources Implications of Robotics*, The W. E. Upjohn Institute for Employment Research, 1983.

Engineering employment in engineering services firms has been growing generally, and if PA consulting and service firms continue to thrive, the share of engineers employed in manufacturing firms (per se) may continue to fall. Although the proportion of manufacturing professional and technical employees represented by engineers has been rising, the proportion of engineers employed in the manufacturing sector is declining. Between 1970 and 1978, the manufacturing sector share of engineer employment fell from 54 to 50 percent, while the (miscellaneous) service share rose from under 13 to 17 percent (see table 21). Within the service sector, engineering employment is concentrated in the engineering and architectural service industry (a group including a large proportion of self-employed professional engineers). That industry was the largest employer of engineers in 1982.[31]

PROJECTED EMPLOYMENT IMPACTS

OTA's case studies and other evidence suggest that, while demand for engineers will increase during this decade, automation will eventually dampen the rate of growth of their employment in manufacturing industries. This is likely because: 1) computer-aided design and engineering increases the output per engineer;* 2) anticipated improvements in such areas as equipment interfaces will solve some of today's problems in applications engineering; and 3) in the long term, if not sooner, there may be some substitution of technician jobs for engineering jobs (see the next section).

Table 21.—Percent Distribution of Engineering Employment by Industry Group, 1970 and 1978

Economic sector	1970	1978
Agriculture, forestry, and fishing	0.18	0.27
Mining	1.73	2.40
Construction	8.29	7.08
Manufacturing	54.26	50.08
Durables	45.82	42.16
Primary metals	2.2	2.01
Fabricated metals	2.46	2.44
Machinery, except electrical and transportation equipment	8.31	8.80
Electrical and electronic machinery	13.23	12.37
Transportation equipment	11.97	10.53
Automobiles	2.17	2.40
Aircraft	8.53	7.02
Professional and scientific instruments	2.36	2.48
Transportation, O.P.U.[a]	7.99	8.55
Wholesale and retail trade	4.32	4.44
Finance, insurance, and real estate	0.71	0.75
Services	12.73	17.01
Commercial R&D	1.06	1.42
Engineering and architecture	7.04	9.63

[a] Other public utilities.

NOTE: Percentages do not sum to 100 due to exclusion of government employment figures.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, *The National Industry-Occupation Employment Matrix, 1970, 1978, and Projected 1990*, April 1981.

Although the complexity of PA installations will grow, so will the capability of automated engineering aids, such as simulation systems, to deal with this complexity. A major aerospace firm, for example, has predicted that its engineering and related technical staff requirements may fall by as much as one-third once the company achieves its automation goals; for some production engineering tasks, the drop may be as high as 80 percent.[32] The aerospace industry represents an extreme case, because the complexity and the stringent quality standards of aerospace products will probably drive major aerospace firms to greater levels of computerization and systems integration, and on a faster timetable, than firms in other industries.

Various trends in industrial organization will also work to slow the rate of growth in engineering employment. For example, the growth in engineering consulting and service firms means that fewer engineers will be employed than would be if producers and users satisfied their needs for engineers internally.

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[30] OTA case study.

[31] Ronald E. Kutscher, "Future Labor Market Conditions for Engineers," paper prepared for the National Research Council Symposium on Labor-Market Conditions for Engineers, Feb. 2, 1984.

*For example, Chrysler expects that its expanded use of CAD will not lead to expansion in employment of engineers and designers using the technology. Rather, the company expects to devote time saved in design and analysis to such other tasks as tooling and product testing. See "Chrysler Expanding CAD Network," *Automotive News*, July 12, 1982.

[32] OTA case study.

Indeed, recent and anticipated growth in engineering and architectural service firms has been attributed in part to shortages of certain types of engineers—in effect, fewer engineers can be spread more thinly by this means.[33] Another factor is growth in the number of automation users who also produce automated equipment and systems. Such user-producers will draw on engineers involved with their own use of automation to produce automated equipment and systems. One reason that Westinghouse, for example, decided to enter the robot market was management's realization that it already had vital in-house engineering expertise.[34] Moreover, when Westinghouse acquired Unimation, it consolidated its robotics work force, since the combined forces of the two firms were believed to be too large.[35]

SHORTAGES OF ENGINEERS

In the near term, engineering employment depends primarily on market conditions and defense spending. Thus, even though they "need" engineers to develop new products, machine-tool builders have laid off engineers because of depressed sales; also, recent engineering graduates have had difficulty getting jobs because of the recessions.[36] Historically, engineers have undergone cycles of shortage and surplus; despite ambiguous evidence, many in industry now believe that a shortage of engineers does or will exist. For example, the Electronic Industries Association recently forecast a shortage of 113,000 electrical and computer engineers by 1987, based on forecasts of engineering graduates and employment targets reported in a survey of 815 manufacturing facilities employing over 736,000 people.[37] However, employer survey data are generally considered unreliable by employment analysts. The shortcomings of this particular survey, for example, were addressed at the February 1984 National Research Council Symposium on Labor-Market Conditions for Engineers.

Drawing on more comprehensive data, the National Science Foundation (NSF) has concluded from a forthcoming study of science, engineering, and technician (SET) personnel needed by defense and civilian industries between 1982 and 1987 that (under conservative assumptions regarding the supply to SET occupations):

1. the only engineering discipline that will experience a shortage, regardless of macroeconomic conditions and defense expenditures, is aeronautical/astronautical (although the sharp drop in the market for aero/astro engineers in 1982-83 may have made this less likely);
2. under stagnant economic conditions and with low defense expenditures, no other engineering discipline will experience a shortage; and
3. with economic growth and high defense expenditures electrical engineers might be in short supply.[38]

NSF and others note that even for a specialized occupational category such as engineers, the supply of labor includes new graduates and immigrants. It also includes movement in from other occupations and movements between disciplines. Such in-mobility is easier for some disciplines (e.g., electrical and electronic) than for others (e.g., aeronautical and astronautical) among engineers.[39]

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[33] *U.S. Industrial Outlook*, Washington, D.C., 1983.

[34] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," Prudential-Bache Securities, Aug. 2, 1983.

[35] "Westinghouse Revamps Robotics; 40 Jobs Lost," *Chicago Sun-Times*, May 22, 1983.

[36] Lauri Gieson, "Engineering Layoffs Raise Questions About the Domestic Industry's Future Strength," *American Metal Market/Metalworking News*, June 18, 1983.

[37] Bill Laberis, "Study Predicts Major Engineer Shortage," *Computerworld*, July 11, 1983.

[38] "Projected Employment Scenarios Show Possible Shortage in Some Engineering and Computer Specialties," *Science Resource Studies Highlights*, National Science Foundation, Feb. 23, 1983. Also, note that "existing Federal programs do not collect data on shortages of workers in specific occupations; such data would be very expensive to collect and because of their complexity their reliability would be questionable." See Neal H. Rosenthal, "Shortages of Machinists: An Evaluation of the Information," *Monthly Labor Review*, July 1982.

[39] Jean E. Vanski, "Projected Labor Market Balance in Engineering and Computer Specialty Occupations: 1982-1987," paper prepared for the Symposium on Labor-Market Conditions for Engineers, National Research Council, Feb. 2, 1984.

Several factors may explain the differences in perception about engineer availability. For the purposes of this study, a principal factor appears to be that employers desire personnel with very specific skills and experience, qualities that data available to modelers (and surveys tallying employment goals) may not reveal. For example, a recruiter from Xerox recently observed:

> We're looking for hardware design engineers and some software people . . . Many of the resumes we see are from people right out of school. Unfortunately, there's nothing for them.[40]

Because it takes time to train engineers and for them to acquire relevant experience, this problem is hard to overcome, especially where technologies are changing rapidly. Furthermore, there is no way to objectively measure the ability of employers to make do with second-choice job candidates, or to restructure their work. On the one hand, such steps bring labor supply into balance with demand. On the other hand, they raise questions about the adequacy of the quality of labor used to meet occupational demands. Also, employees may prefer graduates with the highest grades and/or those from the top schools, a group obviously much smaller than the total graduate pool.

In time, employers may well find that a combination of fewer engineers and automated engineering aids will help them to stabilize their engineering work forces and overcome labor quality problems. Such an approach appears to be taken now with production workers; it may come later for professional and technical workers.

Technicians

A variety of technological and economic factors are contributing to the growth of technician employment in industry; the growing numbers and responsibilities of technicians suggest they are the new "skilled workers" of the economy.

CURRENT EMPLOYMENT TRENDS

Technicians employed in industry are classified as engineering, science, health, or other (not elsewhere classified). Engineering technicians, the principal group within durable manufacturing, include the categories of draftsmen, electrical/electronic engineering, industrial engineering, mechanical engineering, other engineering; NC tool programers may also be considered engineering technicians. Computer programers (business, scientific, and technical) are another important class of technicians in the manufacturing industry. In 1980, combined employment of engineering technicians, NC tool programers, and computer programers was about 1.3 million; it was about 508,000 in manufacturing. In 1982, the total-industry and manufacturing levels were 1.5 million and 518,000, respectively (see table 22).

PROJECTED EMPLOYMENT IMPACTS

Technicians are becoming prominent in PA applications engineering. For example, one company visited by OTA has developed a number of robot applications by teaming engineers with technicians. However, it is not likely that automation will result in a proliferation of narrow technician groups (e.g., "robot technicians") for several reasons. Programing and other preparatory activities can occur relatively infrequently, while production processes and plants generally involve a variety of equipment, making dedicated applications planning or other support personnel unlikely in most cases.

Overall growth among the ranks of technicians does not preclude declines in individual categories. CAD, for example, will reduce demand for draftsmen, unless trends in product markets lead design activity to grow substantially.[41] Increases in productivity through CAD are generally measured as reductions in time relative to conventional drafting to perform a given task, particularly for detailing, revisions, or tests of designs (as distinct from

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[40] Katherine Hafner, "Job Fair Shows Firms Not Seeking Entry-Level DPers," *Computerworld*, May 23, 1983.

[41] Tupperware, for example, increased drafting employment after adopting CAD because the "department is able to produce more." See Joan Faulkner, "Computer-Assisted Drafting," *The Providence Journal*, Oct. 16, 1983.

Table 22.—Combined Employment of Engineering Technicians, NC Tool Programers, and Computer Programers, 1980

	All industries		All manufacturing		Engineering, architectural, and surveying services		Metalworking machinery and equipment		Office computing and accounting machines		Electrical industrial apparatus		Electronic components and accessories		Motor vehicles and equipment		Aircraft and parts	
Engineering and scientific technicians	1,251,955	1.35%	439,852	2.16%	157,550	28.30%	10,303	2.77%	39,858	9.25%	10,107	4.24%	33,783	6.05%	9.182	1.19%	29,225	4.46%
Drafters	315,967	0.34	116,423	0.57	95,988	17.24	6,693	1.80	4,964	1.15	3,096	1.3	3,786	0.68	2,118	0.27	4,751	0.72
Electrical/electronic engineering	358,077	0.39	131,044	0.64	5,814	1.04	1,435	0.39	32,182	7.47	4,501	1.89	21,351	3.82	434	0.06	5,494	0.84
Industrial engineering	32,418	0.03	19,334	0.09	3,670	0.66	788	0.21	NA	NA	782	0.33	497	0.09	537	0.07	1,464	0.22
Mechanical engineering	48,452	0.05	40,775	0.20	2,269	0.41	583	0.16	1,877	0.44	748	0.31	1,796	0.32	2,413	0.31	8,920	1.36
Tool programers, NC	11,907	0.01	9,371	0.05	869	0.16	1,187	0.32	475	0.1	100	0.04	352	0.06	NA	NA	1,076	0.16
Computer programers	226,182	0.24	58,622	0.29	3,303	0.59	755	0.20	19,604	4.55	726	0.3	2,056	0.37	1,166	0.15	2,768	0.42

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

design, per se). Fewer drafting hours, and presumably fewer drafters, are necessary to perform a given amount of work. Also, broader distribution of terminals and workstations, increased CAD/CAE system capabilities, and improved interactivity reduce the rationale for delegating drafting, programing, or data input to specialists. However, the tendency to train and use existing draftsmen in CAD operations is one reason why demand for them is likely to continue for quite some time.[42]

Also, anticipated improvements in equipment integration and interfaces will reduce the occasion for programing. For example, CAD/CAE stations are being developed that will automatically generate (and test) programs for robots or machine tools, and production equipment is being supplied with increasingly easy-to-use software, reducing the need for separate NC tool programers or robot programers. However, development of such systems is ongoing, and stand-alone NC equipment is likely to remain the norm throughout this decade.

As in the case of engineers, trends in industrial organization may also shape employment opportunities for technicians. First, the spread of programmable automation is expected to alter design interactions between prime manufacturers and their suppliers. Automobile and aerospace manufacturers, for example, are increasing computer-links with suppliers for transmission of design specifications. This trend could diminish drafter demand among suppliers. Second, CAD may influence companies' decisions on whether to do their own drafting or have it done on the out-

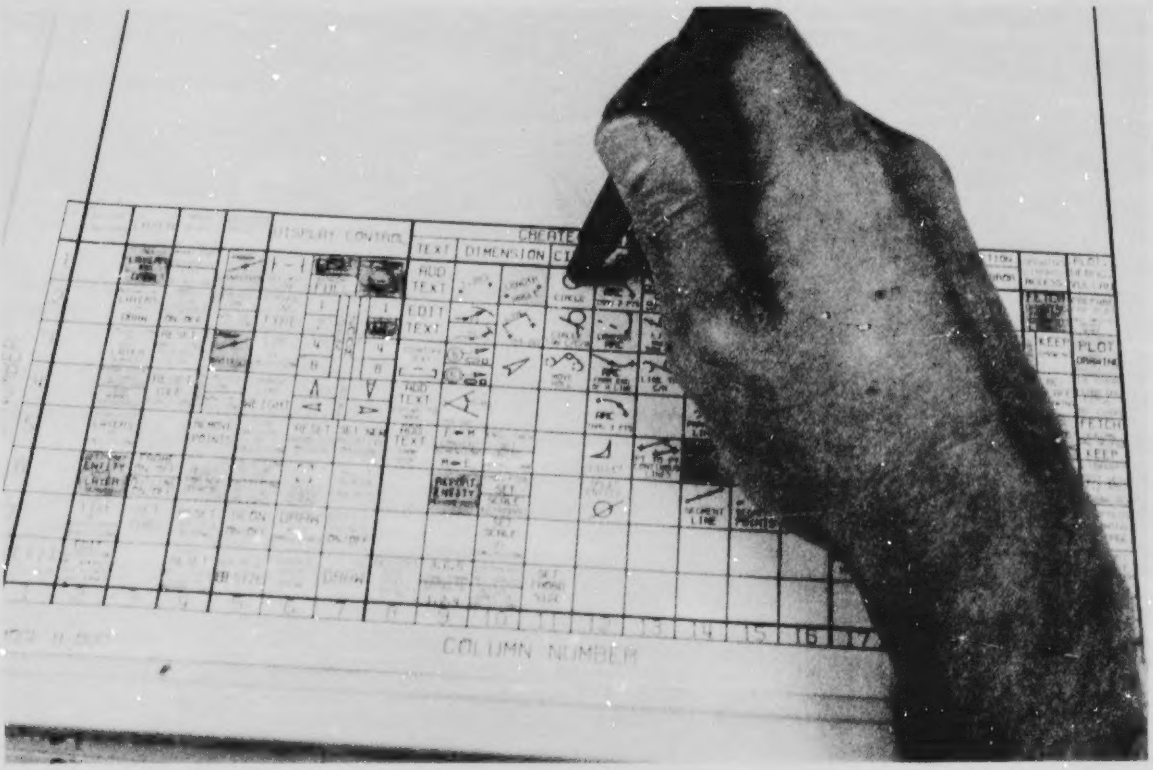

Photo credit: Beloit Corp.

Computer-aided design system "menu" for drafting, with light pen side. A shift to outside drafting, under the assumption that special service firms will be more efficient and productive in drafting activities, would further compress overall demand for draftsmen. Growth in the engineering services market for CAD systems suggests that demand for outside drafting, and perhaps some accompanying demand for outside technicians, may be strong. The manufacturing share of technicians fell between 1970 and 1978 largely because of a growth in the services share.[43] Trends in the 1970's reflect a rapid growth in product complexity and design requirements and the use of both manual and simple CAD systems; the continuation of these trends is thus uncertain.

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[42] OTA case studies; want-ads.

In particular, manufacturers who have the potential to link CAD to production or other equipment may become less interested in buying outside drafting services as design becomes more important in their operations. One research center, for example, created a new job category, "CAD/CAM operator," and hired technicians to work with CAD systems as an alternative to contracting with outside parties for drafting work.[44] Some manufacturers may use their own and outside personnel at the offices of new CAD service firms, which provide computer equipment time and technical support to companies unable to afford their own CAD facilities (see ch. 7).

SUPPLY AND UTILIZATION FACTORS

It is difficult to gauge whether the supply of technicians will be adequate, because persons can become technicians through many avenues that may or may not entail formal "technician training." As will be described in chapter 6, there is evidence that employers are beginning to prefer formal training for technicians, and to offer such training to prepare employees for programmable automation; in addition, independent, outside training is available to individuals to prepare for technician careers. Because their educational requirements are less (in terms of time, money, and rigor) than those of engineers and scientists, the supply of technicians can be increased much faster through appropriate training. This will tend to support proportionate growth in technicians as a class, although it is premature to forecast growth in specific categories.

Because programmable automation lowers the skill requirements for several engineering and production tasks, technicians can and do perform work that previously was considered either professional or skilled trade work. While this may always have taken place, PA is likely to make the substitution possibilities more obvious and numerous. The fact that growth of technician employment in manufacturing between 1977 and 1980 exceeded the growth rate for both scientists and engineers also suggests that technicians are being substituted for other types of personnel. Growing flexibility in staffing again suggests that conventional occupational descriptions and staffing conventions are of limited use for gauging future employment patterns.

Production and Related Workers

This broad category includes "all skilled, semiskilled, and unskilled workers performing machine and manual tasks involving production, maintenance, construction, repair, materials handling, and powerplant operations," as defined by the Bureau of Labor Statistics (BLS). It contains the bulk of the occupations most directly vulnerable to displacement from programmable automation, as well as from past technological changes. Production workers have varied educational backgrounds and skill levels, but are less likely to have college training than are other occupational groups in manufacturing. They tend to acquire their skills on the job rather than through outside training.

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[43] U.S. Department of Labor, Bureau of Labor Statistics, *The National Industry-Occupation Employment Matrix, 1970, 1978, and Projected 1990.* Bulletin 2086 (Washington, D.C.: U.S. Government Printing Office, April 1981). Almost 53 percent of engineering and science technicians were employed in manufacturing in 1970; almost 48 percent were in 1978. During that period, the proportion employed in services rose from over 20 percent to almost 24 percent.

[44] OTA case study.

OVERALL EMPLOYMENT TRENDS

Production and related workers are, overall, the largest occupational group in manufacturing industry employment, with about 14 million employees in 1980. This group's share of manufacturing employment has been declining. In 1980, 68.1 percent of manufacturing employees were production and related workers, compared with 70.8 percent in 1977. This group constitutes the largest proportion of workers in all industries surveyed by BLS in its Occupational Employment Survey (OES) of manufacturing industries. According to 1980 OES data, the highest absolute numbers of these workers are found in the machinery (1.52 million), electrical and electronic equipment (1.25 million), and transportation equipment (1.19 million) industries—the three broad industry groups in which PA is produced and most heavily used.

The group as a whole contains three principal classes of workers, by descending order of skill: craft and related workers, operatives, and laborers. In 1980, there were 3,768,395 craft and related workers, accounting for 18.51 percent of manufacturing employment. This group included 695,157 (3.4 percent of manufacturing employment) mechanics, repairers, and installers; 668,002 (3.3 percent) metalworking craftworkers (excluding mechanics); and 1,751,529 (8.6 percent) others (e.g., welders, painters, etc.). Table 23 details some of the occupations within these categories. In addition, there were 8,845,318 (43.4 percent) operatives. This group included 1,661,150 (8.2 percent) assemblers; 1,470,169 (7.2 percent) metalworking operatives, and 5,713,999 (28.1 percent) other operatives. Finally, there were 1,576,576 (7.7 percent) laborers. Some of the occupations within these categories are listed in table 24. Note that, between 1972 and 1980, production worker employment grew slowly across the economy, with employment among craftworkers growing the most, followed by laborer employment, and with no growth among operatives.[45]

A critical question for future employment levels among production occupations is whether and how much the total amount of domestic production changes; technologies that lower labor input for a given amount of output do not alone lower employment levels. For example, companies using more (or more expensive) equipment because of PA may find operating for more hours in the day more profitable. Adding one or more production shifts is possible if the companies can sell the extra output; it also can increase or sustain company employment. On the other hand, if demand does not support growth in industry output, employment may merely be shifted among firms.

It is important to remember that factors other than automation are motivating declines in production employment among metalworking industries: reductions in the amount and proportion of metal used in a variety of products, and increases in the use of such other materials as plastics and ceramics will reduce employment of metal craftworkers.* However, where the materials shift occurs within a given firm, metalworking employees may move to work with other materials, keeping their jobs but changing their labels. Recent increases in offshore production also depressed domestic employment in metalworking industries, particularly for production and related workers. For example, U.S. auto companies have established component plants offshore, and U.S. aerospace firms have entered into coproduction or other supply agreements with firms located abroad. Increases in imports have a similar effect. Table 25 presents employment in industries particularly affected by foreign trade. As noted above, the growth in foreign sourcing of parts and other products is attributable in part to lower labor costs overseas, although differences in accounting make precise comparisons difficult.

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[45] Carol Boyd Leon, "Occupational Winners and Losers: Who They Were During 1972-1980," *Monthly Labor Review*, June 1982.

*Materials changes also may affect skill requirements. For example, less skilled workers are needed to install plastic piping than metal piping. Within the miscellaneous plastics products industry, craft and related workers comprised 16 percent of 1980 employment, while operatives comprised 56 percent. See James D. York, "Productivity Growth in Plastics Lower Than All Manufacturing," *Monthly Labor Review*, September 1983.

Table 23.—Craftworker Employment and Selected Occupations, 1980
(All manufacturing industries, wage and salary workers)

Occupation	Number	Percent
Craft and related workers	3,768,395	18.51
Construction craftworkers	296,458	1.46
Electricians	126,001	0.62
Plumbers and pipefitters	61,747	0.30
Mechanics, repairers, and installers	695,157	3.41
Air-conditioning, heating, and refrigeration mechanics	11,759	0.06
Aircraft mechanics	19,603	0.10
Automotive mechanics	51,867	0.25
Data-processing machine mechanics	18,050	0.09
Diesel mechanics	3,316	0.02
Electrical instrument and tool repairers	2,979	0.01
Electric motor repairers	1,578	0.01
Engineering equipment mechanics	11,056	0.05
Instrument repairers	22,537	0.11
Knitting machine fixers	10,578	0.05
Loom fixers	17,877	0.09
Maintenance mechanics	209,673	1.03
Maintenance repairers, general utility	181,851	0.89
Millwrights	68,926	0.34
Office machine and cash register servicers	1,864	0.01
Radio and television repairers	5,136	0.03
Section repairers and setters	13,553	0.07
Sewing machine mechanics	12,141	0.06
Metalworking craftworkers, except mechanics	668,002	3.28
Boilermakers	11,966	0.06
Coremakers, hand, bench, and floor	9,107	0.04
Forging press operators	8,727	0.04
Header operators	5,385	0.03
Heat treaters, annealers, and temperers	24,866	0.12
Layout markers, metal	20,664	0.10
Machine tool setters, metalworking	55,312	0.27
Machinists	197,849	0.97
Molders, metal	38,807	0.19
Patternmakers, metal	7,336	0.04
Punch press setters, metal	19,141	0.09
Rolling mill operators and helpers	10,708	0.05
Shear and slitter setters	5,462	0.03
Sheet-metal workers and tinsmiths	80,729	0.40
Tool-and-die makers	158,586	0.78
Printing trades craftworkers	357,249	1.75
Bookbinders, hand and machine	22,674	0.11
Bindery machine setters	6,453	0.03
Compositors and typesetters	105,465	0.52
Etchers and engravers	11,964	0.06
Photoengravers and lithographers	52,601	0.26
Press and plate printers	156,242	0.77
Other craft and related workers	1,751,529	8.61
Blue-collar worker supervisors	705,307	3.46
Cabinetmakers	28,020	0.14
Crane, derrick, and hoist operators	68,589	0.34
Food shapers, hand	4,431	0.02
Furniture finishers	5,756	0.03
Heavy equipment operators	17,052	0.08
Inspectors	433,530	2.13
Jewelers and silversmiths	4,373	0.02
Lens grinders	8,057	0.04
Log inspectors, graders, and scalers	4,701	0.02
Logging tractor operators	13,380	0.07
Lumber graders	5,614	0.03
Machine setters, paper goods	9,955	0.05
Machine setters, plastic materials	7,415	0.04

Table 23.—Craftworker Employment and Selected Occupations, 1980 (All manufacturing industries, wage and salary workers)—Continued

Occupation	Number	Percent
Machine setters, woodworking	5,121	0.03
Millers	6,204	0.03
Patternmakers, wood	6,716	0.03
Patternmakers, n.e.c.	1,374	0.01
Shipfitters	14,389	0.07
Stationary engineers	17,684	0.09
Tailors	8,107	0.04
Testers	104,745	0.51
Upholsterers	20,562	0.10
Upholstery cutters	6,802	0.03
Upholstery workers, n.e.c.	15,495	0.08
Veneer graders	5,055	0.02

n.e.c. = Not elsewhere classified.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and projected 1990 Alternatives," unpublished data on wage and salary employment.

MECHANICS, REPAIRERS, AND INSTALLERS

The spread of programmable automation will increase the proportion and the role of mechanics, repairers and installers (MRI) in manufacturing because it will increase rates of installation and levels of use of equipment, and because both the risk and cost of production stoppage due to equipment malfunction will grow as production becomes more capital-intensive. Though the reliability of individual pieces of equipment appears to be increasing, isolated problems often affect whole systems where equipment is integrated. As manufacturers come to depend more on equipment, their need to be able to respond quickly to problems will grow. In many cases, that need will be met by "throwing people at the problem," although the need to do so may decline as people learn how to develop still better systems. Between 1972 and 1980, data-processing machine repairers experienced one of the largest percentage employment increases among all occupations; employment in this occupation grew 89.4 percent compared to an average rate of 19.1 percent. Note, however, that individual MRI occupations account for very small proportions of industry employment (under 2 percent each). Table 26 shows MRI employment levels for 1980 across manufacturing industries.

Programmable automation will also have a major impact on the types of skills required of mechanics, repairers, and installers. Improvements in diagnostic technologies and the growing tendency to replace rather than repair electronic components have lowered the skill requirements for many specific diagnostic or repair tasks (less skill depth).* On the other hand (as was mentioned earlier), the combination of mechanical, electrical, and electronic features that characterizes programmable automation makes skill breadth necessary for repair and maintenance operations. These operations are likely to involve more, and more varied, tasks than are encountered in repair and maintenance of conventional equipment. In some cases, individuals need broader skills than before because maintenance of automated equipment has been added to other maintenance work while the number of personnel has been kept constant. While individuals may need broader skills, in larger firms repair and maintenance personnel may be deployed in teams of persons with different or overlap-

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*For example, DEC has been developing the "Intelligent Diagnostic Tool" to enable field service personnel to diagnose equipment problems described by customers over the phone. The IDT is based on an expert system. See Martyn Chase, "DEC Says Artificial Intelligence Enabled It To Save $10 Million," *American Metal Market/Metalworking News*, Apr. 4, 1983.

Table 24.—Operative and Laborer Employment and Selected Occupations, 1980
(All manufacturing industries, wage and salary workers)

Occupation	Number	Percent
Operatives	8,845,318	43.44
Assemblers	1,661,150	8.16
Aircraft structure and surfaces assemblers	25,353	0.12
Clock and watch asemblers	4,362	0.02
Electrical and electronic assemblers	232,694	1.14
Electromechanical equipment assemblers	58,174	0.29
Instrument makers and assemblers	24,681	0.29
Machine assemblers	101,043	0.50
All other assemblers	1,214,843	5,97
Bindery operatives	77,918	0.38
Laundry, drycleaning, and pressing machine operatives	57,132	0.28
Meatcutters and butchers	64,015	0.31
Metalworking operatives	1,470,169	7.22
Dip platers, nonelectrolytic	12,768	0.06
Drill press and boring machine operators	124,232	0.61
Electroplaters	36,013	0.18
Furnace chargers	5,520	0.03
Furnace operators, cupola tenders	16,814	0.08
Grinding and abrading machine operators, metal	128,053	0.63
Heaters, metal	6,473	0.03
Lathe machine operators, metal	155,935	0.77
Machine-tool operators, combination	167,942	0.82
Machine-tool operators, numerical control	52,627	0.26
Machine-tool operators, tool-room	38,352	0.19
Milling and planing machine operators	72,061	0.35
Pourers, metal	15,311	0.08
Power brake and bending machine operators, metal	39,877	0.20
Punch press operators, metal	182,364	0.90
Welders and flamecutters	400,629	1.97
All other metalworking operatives	15,198	0.07
Mine operatives, n.e.c.	9,951	0.05
Packing and inspecting operatives	587,631	2.89
Painters, manufactured articles	117,289	0.58
Decorators, hand	4,748	0.02
Rubbers	6,363	0.03
Painters, production	106,178	0.52
Sawyers	76,728	0.38
Sewers and stitchers	845,294	4.15
Textile operatives	378,540	1.86
Transportation equipment operatives	711,195	3.49
Industrial truck operators	269,105	1.32
All other operatives	2,788,306	13.69
Batch plant operators	7,369	0.04
Boring machine operators, wood	4,184	0.02
Coil finishers	7,422	0.04
Cutters, machine	28,048	0.14
Cutters, portable machine	16,472	0.08
Cutter-finisher operators, rubber goods	7,184	0.04
Cutting machine operators, food	11,692	0.06
Die cutters and clicking machine operators	19,680	0.10
Filers, grinders, buffers, and chippers	115,680	0.57
Furnace operators and tenders, except metal	29,378	0.14
Mixing operatives	48,337	0.24
Nailing machine operators	9,352	0.05
Oilers	22,657	0.11
Photographic process workers	12,439	0.06
Power screwdriver operators	8,515	0.04
Punch and stamping press operators, except metal	5,284	0.03
Riveters	14,161	0.07
Sandblasters and shotblasters	10,440	0.05
Sanders, wood	20,684	0.10

Table 24.—Operative and Laborer Employment and Selected Occupations, 1980
(All manufacturing industries, wage and salary workers)—Continued

Occupation	Number	Percent
Shaper and router operators	4,655	0.02
Shear and slitter operators, metal	30,380	0.15
Shoemaking machine operators	64,568	0.32
Winding operatives, n.e.c.	49,157	0.24
Wirers, electronic	30,611	0.15
Laborers, except farm	1,576,576	7.74
Cannery workers	75,066	0.37
Conveyor operators and tenders	31,469	0.15
Furnace operators and heater helpers	8,316	0.04
Helpers, trades	100,752	0.49
Loaders, cars and trucks	5,941	0.03
Loaders, tank cars and trucks	5,579	0.03
Off-bearers	22,499	0.11
Riggers	16,211	0.08
Setters and drawers	7,157	0.04
Shakeout workers, foundry	10,580	0.05
Stock handlers	104,208	0.51
Order fillers	104,208	0.51
Timbercutting and logging workers	36,104	0.18
Work distributors	16,895	0.08
Laborers, except farm, n.e.c.	1,104,071	5.42

n.e.c. = Not elsewhere classified.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and projected 1990 Alternatives," unpublished data on wage and salary employment.

ping skills, although this may result from work rules established by labor contracts as well as the changing demands of technology.

The potential for long-term growth in absolute numbers of mechanics, repairers, and installers is uncertain. Several factors will limit that growth. First, where small, stand-alone systems are used, vendors or existing maintenance personnel are likely to repair the new equipment. For example, a producer of shoe-manufacturing machinery who installed a single welding robot in an old facility simply trained its existing electrician to repair the robot.* Where installations involve a lot of equipment, especially if integrated, new maintenance personnel may be added. One automobile manufacturer, for example, took on several new repair personnel to service an automated welding system.[46]

The fact that more hardware may be used for a given amount of manufacturing implies that more maintenance personnel will be needed, but experience suggests that for each user there is a threshold level of new equipment that must be attained before new personnel are hired. That level varies substantially among companies and industries. Also, automation of diagnostic and repair procedures reduces the amount of diagnosis and repair work. These developments, and related trends such as growth in service hot-lines and equipment communications links, will dampen the potential growth in maintenance personnel. Finally, computerization generally carries with it new needs for maintenance of software, although this work has typically been done by people classified as "data-processing professionals," rather than production workers.

One development in particular that may curb employment growth for mechanics, repairers, and installers is equipment and system insurance. Companies may choose to insure against the loss (of equipment and/or profit) associated with a breakdown as an alternative to protecting against that loss by employing a lot of machinists or repairmen. There is evidence that some companies have been making such a choice while using conventional equipment; the number of losses re-

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*OTA site visit.

[46] OTA case study.

Table 25.—Trade-Sensitive Employment

Input-Output class[a]	Industry description	Net trade-related job opportunities		Change in net trade-related job opportunities between 1964 and 1975		
		1964	1975	Total	Direct	Indirect
The 20 industries in which job opportunities were most adversely affected by trade between 1964 and 1975						
1804	Apparel, purchased	-41,569	-144,932	-103,363	-87,048	-16,315
5903	Motor vehicles and parts	12,256	-63,939	-76,195	-54,299	-21,896
3701	Furnaces, steel products	10,055	-36,447	-46,502	-32,825	-13,677
3402	Nonrubber footwear	-8,570	-46,315	-37,745	-36,790	-957
6105	Motorcycles, bicycles, and parts	-7,150	-29,817	-22,667	-19,980	-2,687
5601	Radio and television sets	-5,581	-25,986	-20,405	-19,098	-1,307
1601	Broadwoven fabric mills	-22,688	-40,815	-18,127	7,810	-25,937
3202	Rubber footwear	-4,601	-15,292	-10,691	-10,377	-314
3101	Petroleum refining	-2,190	-12,395	-10,205	-9,843	-362
2307	Furniture and fixtures, n.e.c.	-3,101	-13,094	-9,993	-9,933	-66
5104	Office machines, n.e.c.	-700	-9,235	-8,535	-8,329	-206
3403	Other leather products	-7,337	-15,647	-8,310	-7,898	-412
5701	Electron tubes	359	-7,443	-7,802	1,022	-8,824
1802	Knit apparel mills	-3,186	-9,946	-6,760	0	-6,760
2801	Plastic materials and resins	9,923	3,531	-6,392	-5,493	-899
4802	Textile machinery	4,325	-1,805	-6,130	-5,519	-611
1903	Fabricated textiles, n.e.c.	4,149	-1,714	-5,863	-1,709	-4,154
4701	Machine tools, metal cutting types	9,388	3,558	-5,830	-6,161	331
2201	Wood household furniture	-96	-5,242	-5,146	1,324	-6,470
3201	Tires and inner tubes	1,722	-3,357	-5,079	-3,882	-1,197
The 20 industries in which job opportunities were most favorably affected by trade between 1964 and 1975						
6001	Aircraft	22,633	76,683	54,050	48,104	6,036
6004	Aircraft equipment, n.e.c.	33,246	78,542	45,296	19,507	25,789
5101	Computing machines	16,183	54,666	38,483	32,544	5,939
2001	Logging	-17,967	8,278	26,245	13,785	12,460
4503	Oil field machinery	6,410	26,915	20,505	19,313	1,192
4501	Construction machinery	30,094	47,720	17,626	16,267	1,359
5301	Electric measuring instruments	4,897	17,671	12,774	11,671	1,103
2002	Sawmills and planing mills	-31,566	-19,372	12,194	10,021	2,173
6002	Aircraft engines and parts	15,769	26,201	10,432	3,812	6,618
2402	Paper mills	-23,444	-13,154	10,290	9,518	772
4806	Special industrial machines	11,738	21,392	9,654	9,134	520
4901	Pumps and compressors	7,711	17,006	9,295	7,598	1,697
5304	Motors and generators	9,244	16,473	7,229	5,267	1,962
5503	Wiring devices	4,351	11,458	7,107	4,440	2,667
5703	Electronic components	15,371	21,990	6,619	5,138	1,481
5702	Semiconductors	4,984	11,182	6,198	4,961	1,237
2006	Veneer and plywood	-13,734	-7,669	6,065	4,806	1,259
4006	Fabricated plate work	6,664	11,926	5,262	4,401	861
5203	Refrigerator machines	5,932	11,120	5,188	6,154	-966
5000	Machine shop products	12,128	17,204	5,076	1,612	3,464

[a] The concordance between I-O (input-output table) classifications and standard industrial classifications is published in *Survey of Current Business*, February 1974.
n.e.c. = Not elsewhere classified

SOURCE: Gregory K. Schoepfle, "Imports and Domestic Employment: Identifying Affected Industries," *Monthly Labor Review*, August 1982.

corded by insurers that are attributed to inadequate maintenance is growing. Historically, U.S. casualty and property insurers have refused to insure computers and computerized equipment. However, Kemper has recently decided to cover such equipment under its boiler and machinery program, and other insurance companies are expected to follow suit.[47] Meanwhile, the American press has treated the offering of "robot insurance" in Japan as an oddity.

OTHER CATEGORIES

The remaining categories of production and related workers—**metalworking and other craftworkers, operatives, and laborers**—are to varying degrees likely to experience displacement due to programmable automation, other

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[47] Bob Nielsen, Kemper Insurance, personal communication, November 1983.

Table 26.—Employment of Mechanics and Related Personnel, 1980

	All manufacturing		Metalworking machinery and equipment		Office computing and accounting machines		Electrical industrial apparatus		Electronic components and accessories		Motor vehicles and equipment		Aircraft and parts	
MRI[a] and construction craftworkers	991,615	4.9%	7,292	2.0%	19,097	4.4%	8,666	3.6%	14,976	2.7%	44,497	5.8%	40,190	6.1%
Electricians	126,001	0.6%	1,955	0.5%	813	0.2%	1,451	0.6%	1,762	0.3%	9,268	1.2%	3,597	0.6%
Data-processing machine mechanics	18,050	0.09%	NA		14,296	3.32%	191	0.08%	312	0.06%	NA	NA	382	0.06%
Instrument repairers	22,537	0.1%	NA	NA	NA	NA	172	0.07%	285	0.05%	319	0.04%	2,149	0.3%
Maintenance repairers, general utility	181,851	0.9%	1,642	0.4%	1,528	0.4%	1,552	0.7%	4,378	0.8%	2,122	0.3%	1,598	0.2%
Electric motor repairer	1,578	0.01%	—		—		1,073	0.5%	151	0.03%	—		—	
Electrical instrument tool repairer	2,979	0.01%	—		—		134	0.06%	1,326	0.24%	—		—	

[a] MRI – Mechanics, repairers, and installers.

NA – Not available.

NOTE: Percentages have been rounded.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

things being equal. This group, which dominates manufacturing employment, numbered over 12 million in 1980.

There are no simple rules about how automation displaces production workers; however, it is clear that as long as production volume is constant and automation improves productivity (or as long as volume grows significantly less than productivity), it will displace production jobs. By design, such innovations as automated controls, the use of robots and other manipulators to load and unload machines, flexible fixtures (which are replaced or adjusted less often than conventional ones), the linking of automated production and materials handling equipment into systems, and the use of computers to regulate the flow of materials and work-in-process will: 1) reduce the amount and type of human activity required in any given operation, and 2) decrease the number of workers required to perform a given amount of work. Robots, for example, are currently not faster than people for most applications, but they may be more consistent, performing with fewer errors over time and taking less time to achieve a given level of quality.

In practice, the potential for displacement will vary enormously by application and facility. For some applications, one "operator" may be needed at one machine; for others, one person may tend several machines. In many cases, the linking of activities by automated materials handling (robotic or other) will reduce the labor component for setup; both trends will increase the machine-to-person ratio.

Throughout this decade, technological limitations (particularly in the areas of sensors and interfaces) are likely to restrict the tasks in which PA may be used, and economic considerations will continue to moderate the rate of diffusion and the extent to which products and processes are redesigned. Looking toward the future, no case-by-case evaluation of occupations can convey the potential for displacement implied by the integration of manufacturing equipment and systems because it cannot capture all of the indirect impacts on staffing. Experience with highly integrated systems is quite limited, and it shows that initial applications using current technology require more labor than had been anticipated. The employment effects of highly integrated systems are not likely to be significant until at least the 1990's, and even then are likely to remain concentrated in the machinery and transportation equipment industries.

The problems in gauging displacement from PA overall can be illustrated by examining the cases of welders and flamecutters, painters, and machinists. **Welders and flamecutters** numbered 400,629 (1.97 percent of manufacturing employment) in 1980, and **production painters** numbered 106,178 (0.52 percent). Table 27 shows their distribution across selected metalworking industries. While automatic welding machines have been available for some time, interest in using robots for welding and spray painting was a major factor in the commercialization of robot technology. A principal motivation for these robot applications, in addition to the prospect of lower labor costs,

Table 27.—Distribution of Flamecutters, Welders, and Production Painters in the Metalworking Industries, 1980

	Welders and flamecutters		Production painters	
	Number	Percent	Number	Percent
All manufacturing	400,629	2.0%	106,178	0.5%
Metalworking machinery and equipment	6,562	1.8	1,284	0.4
Office, computing, and accounting machines	2,094	0.5	1,172	0.3
Electrical industrial apparatus	3,872	1.6	1,195	0.5
Electronic components and accessories	2,405	0.4	1,229	0.2
Motor vehicles and equipment	41,159	5.3	13,556	1.8
Aircraft and parts	6,193	0.9	4,295	0.7

NOTE: Percentages have been rounded.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

was the elimination of particularly unpleasant and hazardous work.

It is easier to gauge displacement potential for these occupations than for others because the source of displacement appears limited to a single automation technology, robots. However, all welders and production painters are not alike. Those whose work is most monotonous and unpleasant are most likely to be displaced, other things being equal; that category includes spot welders and spray painters in the auto industry. By contrast, it is less applicable to welders in the aircraft industry, who are more likely to do arc welding. Although sensor and machine vision advances will make arc welding increasingly susceptible to automation during this decade, it is not clear whether automated welding will ever be of sufficiently high quality to displace large proportions of these workers. Also, because much arc welding is not done in a mass-production context (like automotive spot welding), human performance may be more economical in many cases.

Even with automation of welding and painting, human input is still required for setup, supervision, inspection, adjustment, and/or retouching, because of the shortcomings of automated equipment. Painting is easier to automate than welding because it is easier to control the quality of the work. Improvement in automated inspection systems is likely to reduce, but not eliminate, the labor component needed for supervision, inspection, adjustment —and therefore retouching—by the 1990's. The Upjohn Institute robotics study concluded that 15 to 20 percent of welding jobs and 27 to 37 percent of painting jobs in the auto industry (3 to 6 percent and 7 to 12 percent, respectively, for jobs in all other manufacturing industries) could be displaced by robots by 1990; Ayres and Miller estimated that between about 93,000 and 169,000 welders and between about 35,000 and 52,000 painters could eventually be displaced by robots, depending on the level of sophistication.[48]

The displacement potential for machinists is much less clear-cut. There were 197,849 machinists (0.97 percent of manufacturing) employed in manufacturing in 1980, according to OES. BLS recently addressed the question of machinist employment, drawing on Current Population Survey (CPS) as the richest data source for this purpose.[49] According to the CPS, which also provides detailed data on other skilled and operative machining occupations, there were 567,000 machinists in 1980; there were 834,000 total skilled machine workers, including machinists, job and die setters, and tool and die makers.

While NC machining can do some tasks that are beyond the capabilities of people working with conventional machine tools, a principal motivation in the development and spread of NC equipment has been alleged shortages of machinists, who are highly skilled, well-paid craftsmen. Between 1972 and 1980, CPS data show that machinist employment rose by 190,000, while employment in other skilled machining occupations fell. For purposes of comparison with other occupational statistics presented in this chapter, table 28 presents machinist employment levels in several metalworking industries according to OES data.

The proportion (and number) of skilled machinists is likely to fall in the long term because of growing use of NC technology, especially among smaller firms, and because of constraints on supply. This will happen because in some cases NC allows less skilled people to substitute for skilled journeyman machinists in operating and/or programing machine tools.

> One major response from management to the skills shortage has been to de-skill the work the journeyman once handled himself. In effect, one job is broken down into its various elements and then distributed among workers who are able to learn these smaller tasks.[50]

Meanwhile, entry into skilled machinist jobs is limited by the need for a lengthy skill-acquisition process (apprenticeships, for exam-

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[48] Hunt and Hunt, op. cit.; and Robert U. Ayres and Steven Miller, "Robotics, CAM, and Industrial Productivity," *National Productivity Review*, winter 1981-1982.

[49] Neal H. Rosenthal, "Shortages of Machinists: An Evaluation of the Information," *Monthly Labor Review*, July 1982.

[50] Daniel D. Cook and John S. McClenahen, "Skilled Worker Nears Extinction," *Industry Week*, Aug. 29, 1977.

Table 28.—Machinist Employment, 1980

	Machinists		Machine toolsetters, metalworking		Tool and die makers	
	Number	Percent	Number	Percent	Number	Percent
All manufacturing	197,849	1.0	55,312	0.3	158,586	0.8
Metalworking machinery and equipment	19,181	5.2	3,112	0.8	42,356	11.4
Office, computing, and accounting machines	1,987	0.5	1,063	0.3	1,849	0.4
Electrical industrial apparatus	2,701	1.1	1,630	0.7	2,638	1.1
Electronic components and accessories	4,108	0.7	708	0.1	3,599	0.6
Motor vehicles and accessories	2,468	0.3	9,993	1.3	11,811	1.5
Aircraft and parts	7,251	1.1	4,738	0.7	6,214	1.0

NOTE: Percentages have been rounded.
SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

ple, usually last 4 years).* Consequently, although the need for highly trained machinists varies among firms and industries, it is likely that the overall level of metalworking skills will drop because machinists are among the most skilled of metalworking craftsmen.

At least in the short term, however, increases in defense expenditures will certainly lead to shortages of machinists—which will in turn spur the introduction of NC. A recent study performed by Data Resources, Inc., for the U.S. Department of Defense, forecasts shortages of machinists and other metalworking personnel by 1987. It concludes that defense expenditures will account for almost 60 percent of the growth in machinist demand between 1981 and 1987 (compared to a defense share of 120 percent for assembler-demand growth and 87 percent of metalworking operative demand growth).[81] While that study does not appear to account for metalworking technology changes, and may therefore overstate the potential for shortages, it underscores the importance of production volume as a major influence in employment opportunities. One reason behind the belief in a machinist shortage is the cyclical nature of machinist demand; the unevenness in metalworking product demand, especially that which is associated with defense spending, tends to place employers in a hiring position when demand surges.

Two groups of relatively low-skilled production workers, **materials handlers and assemblers**, may be quite vulnerable to displacement in the long run. Various forms of automated materials handling, robots, and automated storage and retrieval systems (AS/RS) can substitute for such materials handlers as conveyor operators; crane, derrick, and hoist operators; and industrial truck operators. Manufacturing employment in these categories totaled 370,000 in 1980. For example, central control computers for automatic guided vehicle systems can monitor location, load, and obstacles, and issue commands to vehicles in response to problems. PA can also replace people who manually load, unload, and transfer materials. For example, in plastics processing, robots perform such tasks as lifting, tilting, twisting, positioning, aligning, and transferring items; loading and unloading machines; and handling and orienting finished parts. Materials handling employment will also be affected by procedural changes, such as adoption of "just-in-time" delivery of supplies; the use of manufacturing resources planning (MRP) and other systems to rationalize the flow and use of materials; and other measures to reduce inventories.

The biggest changes in materials handler employment, at least in the near term, will come in large establishments. Large firms and

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*Surveys show that industry efforts to increase machinist supply have been limited. According to one: "In some areas, it apparently is not a scarcity of journeymen but the price tag they bear—and industry's willingness to meet it—which effectively results in a skills shortage." See Daniel D. Cook and John S. McClenahen, "Skilled Worker Nears Extinction." *Industry Week*, Aug. 29, 1977, and "Attitudes Toward the Skilled Trades: Employment Issues in the Precision Metalworking Industry," report of a survey conducted for Sentry Insurance on behalf of the Task Force on the Skilled Trades Shortage by Louis Harris and Associates, Inc., November 1982.

[81] Ralph M. Doggett, "Regional Forecasts of Industrial Base Manpower Demand, 1981 to 1987," prepared for the Office of the Under Secretary of Defense for Research and Engineering by Data Resources, Inc., March 1983.

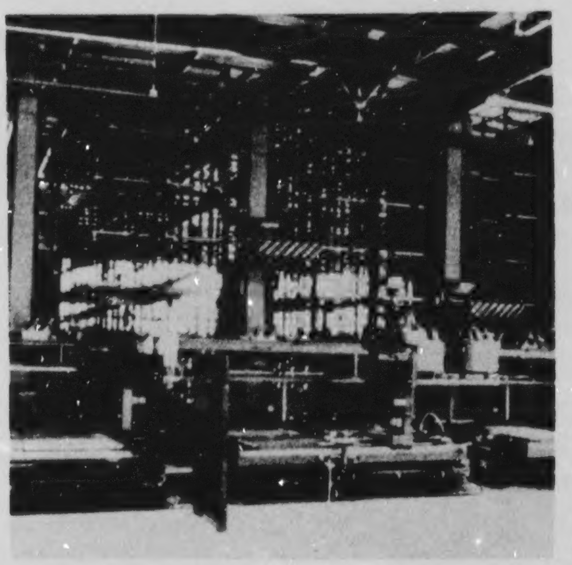

Photo credit: Cincinnati Milacron, Inc.

Automated materials handling, storage, and retrieval, with automated guided vehicles

plants are more able and likely to install AS/RS, can most easily implement MRP, and are more likely to link automated materials handling to production activities.* Materials handling robot applications are more practical for a wide range of firm sizes and industries, but are relatively limited at present (see ch. 3). Also, even where production is highly automated, labor is used for the initial input and/or final removal of materials from the system or the transfer from one stage to another. In contemplating flexible manufacturing systems, for example, it can be misleading to look only at the automated operations instead of the entire production process.

Assemblers perform tasks that range from the insertion of electronic components into circuit boards to building aircraft. In 1980, there were 1,661,150 (8.16 percent of manufacturing) assemblers in manufacturing. Table 29 shows their distribution across selected metalworking industries. The degree of complexity and margin for error of specific assembly tasks govern their ease of automation. Sensor and machine vision technologies can improve the precision and consistency of automated assembly equipment, and assembly applications of robots are expected to grow by the end of this decade. For example, the Upjohn Institute estimated that robots could displace 1 to 3 percent of assemblers by 1990 (including 5 to 10 percent of auto-industry assemblers); Ayres and Miller estimated that robots could ultimately displace between about 132,000 and 396,000 assemblers, depending on technological sophistication, in metalworking industries.[52]

The vulnerability of assemblers to displacement varies substantially by product type. For example, with miniaturization many electronics products cannot be assembled (or inspected) adequately by people. Also, many electronics products must be assembled in sterile environments where managers aim to minimize all sources of contaminants, including those naturally conveyed by people. In these cases, special equipment, not necessarily programmable, may be designed to do assembly and inspection work. Improvements in

Table 29.—Employment of Assemblers in Selected Manufacturing Industries, 1980

	Number	Percent
All industries	1,661,201	1.8%
All manufacturing	1,661,150	8.2
Metalworking machinery and equipment	24,779	6.7
Office, computing, and accounting machines	85,714	19.9
Electrical industrial apparatus	50,987	21.4
Electronic components and accessories	169,759	30.4
Motor vehicles and equipment	175,922	22.7
Aircraft and parts	64,126	9.8

NOTE: Percentages have been rounded.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

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*One gauge of potential changes in materials handling (especially for larger facilities) is the experience of food warehousers, many of which have implemented AS/RS. For example, B. Green & Co., a Baltimore full-line food wholesaler, hoped to triple its business by opening a new $22 million semiautomated warehouse and consolidating activities presently conducted at several locations. The company expected to lay off about 60 workers, most of them part-time. See Joyce Price, "60 Workers Lose Out to Automation," *The News American*, March 1983.

[52] Hunt and Hunt, op. cit.; and Ayres and Miller, op. cit.

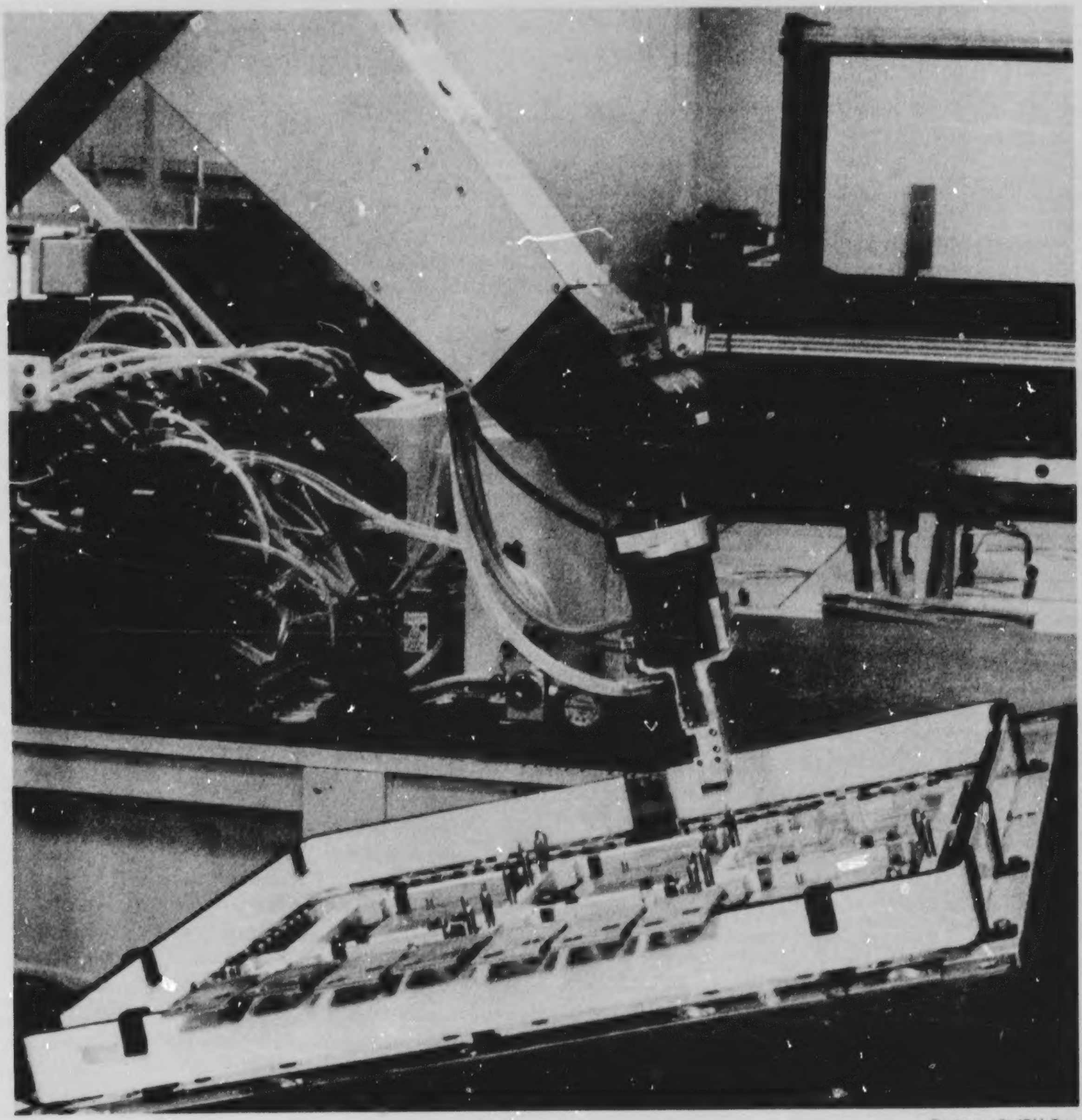

Photo credit: IBM Corp.

Electronics assembly application: Close-up of robot arm with small resistor pack ready for insertion in printed circuit board socket product design, often associated with the adoption of PA, will also reduce the amount of (or at least simplify) assembly work needed in manufacturing. For example, GE invested $38 million in a highly automated dishwasher factory and redesigned the products, reducing the number of different parts handled from 4,000 to 800.[53]

Note that **inspectors** may be affected by similar developments as assemblers, including improvements in sensor technology. In 1980 there were 433,530 manufacturing inspectors (2.13 percent of manufacturing). Table 30 shows the distribution of inspectors in selected metalworking industries. Many observers believe that the role and number of inspectors and other quality-control personnel will diminish as companies move from end-of-the-line quality-control inspection to in-line quality assurance. This will often happen as a consequence or corollary of automating. At least one company, for example, offers statistical process-control software in conjunction with its line of robots. General Motors, for example, expects that a combination of statistical process control, just-in-time supply scheduling, and other measures will substantially reduce the amount of receiving work in its new "Buick City" complex.[54]

Table 30.—Employment of Inspectors, 1980

	Number	Percent
All industries	471,984	0.5%
All manufacturing	433,530	2.1
Metalworking machinery and equipment	5,781	1.6
Office, computing, and accounting machinery	12,991	3.0
Electrical industrial apparatus	6,744	2.8
Electronic components and accessories	22,072	4.0
Motor vehicles and equipment	38,769	5.0
Aircraft and parts	28,914	4.4

NOTE: Percentages have been rounded.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

Finally, some new production jobs may emerge as an indirect result of changes in production processes and/or organizational procedures associated with PA. For example, when an auto manufacturer introduced a multi-robot spot-welding system, it began to produce major auto-body parts with corresponding notches and tabs which are connected prior to automated welding by an individual on the line; this new job is called "toy-tabbing." At an aircraft manufacturer, the introduction of an automated monitoring system for an automated machine shop was accompanied by the introduction of relief operators, a group of individuals who substitute temporarily for full-time staff.[55] In some cases, these new jobs may be transient, reflecting the requirements of a given level of automation, while in other cases they may be long-term, reflecting enduring changes in production processes. (Transient skill requirements are discussed more fully in a later section of the chapter.) In any event, these are jobs that are most likely to be filled through the transfer and retraining of existing personnel. The creation of new jobs is perhaps the hardest employment impact to forecast.

Clerical Workers

CURRENT EMPLOYMENT TRENDS

Clerical workers in manufacturing industries perform a variety of functions in both office and plant settings. Across manufacturing industries, 2,322,400 (11.5 percent) were employed in clerical positions in 1980; 2,215,334 (11.8 percent) were so employed in 1982, when economy-wide clerical employment was over 18.7 million (20 percent of total employment). Now, manufacturing technologies will affect both office and plant clerical workers, and the growing use of office automation will reinforce the displacing effects of PA in manufacturing. Table 31 shows the distribution of potentially vulnerable office and plant clerical occupations in selected metalworking industries.

Past growth in clerical employment in manufacturing, as in the rest of the economy, has reflected a substantial growth in company de-

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[53] Bruce Vernyi, "Automated Dishwasher Plant Opens," *American Metal Market/Metalworking News*, May 2, 1983.

[54] Al Wrigley, "GM Awards Buick City Contract to Progressive," *American Metal/Metalworking News*, Aug. 15, 1983.

[55] OTA case studies.

Table 31.—Clerical Employment, 1980

	All industries		All manufacturing		Metalworking machinery and equipment		Office, computing, and accounting machines		Electrical industrial apparatus		Electronic components and accessories		Motor vehicles and equipment		Aircraft and parts	
Office machine operators	912,708	1.0%	147,499	0.7%	2,311	0.6%	6,762	1.6%	1,704	0.7%	3,302	0.6%	3,431	0.4%	6,424	1.0%
Computer operators	184,245	0.2	36,945	0.2	676	0.2	3,170	0.7	NA	NA	1,140	0.2	1,029	0.1	1,142	0.2
Order clerks	242,547	0.3	68,604	0.3	927	0.3	919	0.2	1,021	0.4	1,491	0.3	734	0.1	1,281	0.2
Payroll and timekeeping clerks	177,785	0.2	60,412	0.3	1,104	0.3	870	0.2	668	0.3	1,284	0.2	1,160	0.2	1,558	0.2
Personnel clerks	94,829	0.1	25,376	0.1	356	0.1	873	0.2	305	0.1	904	0.2	334	0.04	2,239	0.3
Procurement clerks	40,274	0.04	24,551	0.1	550	0.2	1,035	0.2	462	0.2	1,046	0.2	488	0.06	1,882	0.3
Production clerks	200,029	0.2	139,947	0.7	2,910	0.8	7,121	1.7	2,889	1.2	6,099	1.1	4,778	0.6	13,219	2.0
Shipping and receiving clerks	389,218	0.4	146,036	0.7	1,908	0.5	2,118	0.5	1,409	0.6	3,550	0.6	5,246	0.7	2,679	0.4
Stockroom and warehouse clerks	818,435	0.9	151,043	0.7	4,469	1.2	6,806	1.6	2,988	1.3	4,299	0.8	5,187	0.7	10,333	1.6
All clerical	18,521,980	20.0	2,297,379	11.3	40,429	10.9	69,320	16.1	28,213	11.9	57,235	10.3	47,973	6.2	90,760	13.9

NOTE: Percentages have been rounded.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990 Alternatives," unpublished data on wage and salary employment.

mand for information collection and processing, growth that has been facilitated by early uses of computers and office automation. Note that the continued presence of large numbers of keypunch operators attests to the slowness with which companies make major changes in data-handling and data-processing systems, especially those that represent major investments in hardware.

PROJECTED EMPLOYMENT IMPACTS

Programmable automation will affect clerical employment by computerizing the "paper trail" that follows materials and work-in-process through production. This is a direct outcome of the data-aggregating function of PA systems, which relate all types of tasks, from design through shipment, to a manufacturing database. Indeed, the Air Force ICAM program targets such functions as planning, scheduling, and other indirect or nonproduction functions, which underlie much production clerk employment, as principal candidates for automation. The development and storage of product plans through computer-aided design, the direct linkage of CAD to production equipment, and the computerization of planning, ordering, purchasing, billing, and inventory control will all act to reduce the demand for clerical services and personnel.

Clerical employment is most likely to change, at least in the near term, among larger firms because they are quicker to adopt computerized inventory and planning systems, and because they have greater information-flow needs and problems. For example, the Litton Office Product Center installed an automated system for order entry, inventory checking, receivable monitoring, and billing which cut time for these activities by 75 percent.[56] Larger firms are also more likely to adopt sophisticated automated materials handling systems and AS/RS, which is most economical in larger installations. Finally, reductions in company work forces as well as automated recordkeeping may affect personnel and payroll clerk employment. Of all occupational groups, production clerks, together with such other intermediaries as stockchasers and expediters, rank among the most likely to diminish in size with extensive automation and computer-integration.

Managers

Managers plan, organize, direct, and control various functions within firms. They may also do work similar to that of their subordinates.

CURRENT EMPLOYMENT TRENDS

In 1980, there were 1,328,160 managers and officers across the manufacturing sector, accounting for 6.58 percent of manufacturing employment. In 1982, there were 1,260,062 (6.7 percent). Nationally, employment of managerial personnel has been growing in all economic sectors, even during the recent recessions.* There were about 7.7 million managers, officials, and proprietors in 1982 nationwide. Lower level managers include "nonworking" or "blue collar" supervisors and clerical supervisors, who are counted with production and clerical workers, respectively. There were 705,307 (3.46 percent) blue collar supervisors and 66,841 (0.33 percent) clerical supervisors in manufacturing in 1980. Table 32 shows the distribution of managerial and supervisory personnel in the machinery and transportation equipment industries.

PROJECTED EMPLOYMENT IMPACTS

Programmable automation will alter the mix and number of managerial personnel. It will probably support growth in upper management ranks, for three reasons. First, the integration of databases and anticipated shifts in decisionmaking toward higher staff levels will increase the role of upper management in the production process. The push for so-called "top down control," facilitated by computerization, inherently increases the role of upper

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[56] Paul Gillin, "Last Piece of Automation Puzzle Fits for Firm," *Computerworld*, Dec. 5, 1983.

*There were nearly 7 percent more managers and administrators in December 1982 than in January 1980, while overall employment fell 1 percent; however, unemployment for managers also grew in that period. See Karen W. Arenson, "Management's Ranks Grow," *The New York Times*, Apr. 14, 1983.

Table 32.—Employment of Managerial and Supervisory Personnel, 1980

	Managers, officials, & proprietors		Nonworking blue-collar supervisors		Clerical supervisors	
	Number	Percent	Number	Percent	Number	Percent
All industries	7,557,359	8.1	1,273,191	1.4	428,087	0.5
All manufacturing	1,195,743	5.9	705,307	3.5	66,841	0.3
Metalworking machinery and equipment	28,190	7.6	10,119	2.7	862	0.2
Office, computing, and accounting machines	40,583	9.4	8,112	1.9	2,473	0.6
Electrical industrial apparatus	12,632	5.3	8,343	3.5	1,009	0.4
Electronic components and accessories	29,954	5.4	15,928	2.9	1,936	0.4
Motor vehicles and equipment	25,424	3.3	30,575	4.0	1,110	0.1
Aircraft and parts	48,746	7.4	24,391	3.7	1,914	0.3

NOTE: Percentages have been rounded.
SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990," unpublished data on wage and salary employment.

management. Second, insofar as batch production, product variation, and competition grow, more managerial input will be required for product planning and market analysis. Growth in PA products and markets is itself a source of growth in managerial employment; many want-ads for managers refer to planned or existing new ventures, and they often refer to marketing responsibilities. Third, change in production technologies may create new operational units within firms, and associated needs for planning and management. Automation generally entails new work in database management, software quality assurance, and training—activities which may be undertaken by special staffs and managers.

Nevertheless, it is not clear how much new managerial employment the support needs of manufacturing automation will generate, especially where companies already have data-processing staffs. Also, more advanced systems that do not require mastery of special languages or formats, that include applications generators, or that entail distributed data processing lower the requirement for special, in-house personnel.

By contrast, the automation of data collection and transfer activities (e.g., through monitoring operation and performance characteristics of machines, and developing and transmitting machine operating instructions from CAD systems) is expected to lower the demand for lower and middle managers.[57] Some observers predict that this will lead to an hourglass personnel structure among firms. In some cases, automation may bring about an upgrading of a management position. For example, added attention to materials requirements, production planning, and scheduling may make certain materials and inventory management activities into "white collar" functions. Where a few employees oversee a larger amount of equipment, fewer first-line supervisors may be needed. Indeed, with integrated systems, it is likely that a hybrid position containing attributes of formerly separate supervisory and subordinate operator jobs may emerge.

Other changes in the nature of managerial work are possible. A study evaluating prospects for computer operations managers generally suggested growing needs for capacity planning, performance monitoring, technical support, security management, and facilities management.[58] Also, a study of manufacturing firms concluded that:

> The new technology substantially changed the jobs of supervisors and middle-management, shifting the focus from watchdog and disciplinarian to planning, training, and communicating.[59]

Industry representatives frequently point to resistance among lower and middle management as a principal obstacle to the spread of automation. Greater recognition of the potential of these technologies to displace such personnel may add to such problems.

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[57] David Myers, "ACM Told OA May Squeeze Middle Managers Out of Jobs," *Computerworld*, Oct. 31, 1983.

[58] "Higher Skills Needed: Study," *Computerworld*, Apr. 18, 1983.

[59] Wickam Skinner, "Wanted: Managers for the Factory of the Future," *The Annals of the American Academy of Political and Social Science*, vol. 470, November 1983.

Sales/Service

Sales and technical service personnel consult with potential and actual customers, conduct presentations and demonstrations, provide training, and install products. In 1980 there were 437,497 (2.15 percent) sales workers employed in manufacturing. In 1982, there were 413,657 (2.2 percent). These included sales representatives or agents and sales clerks. Also in 1980, there were 5,165 (0.03 percent) adult education teachers employed in manufacturing industries. Finally, technical writers (in unknown number) comprise a related category.

Producers of PA, as well as independent consulting or service firms, are likely to demonstrate a growing need for technical sales and service or support personnel to serve their growing markets. On the other hand, automated management and office systems are likely to dampen demand for sales clerks.

Although industry representatives have complained of shortages of field-service personnel and trainers, it is difficult to judge the numbers of such people, because in many cases they wear several hats. Also, for products that are new and continually developing, it is to be expected that people with relevant expertise may be hard to find. For smaller, innovative firms, in particular, technology sales and support personnel tend to be engineers and other professionals. However, want-ads suggest that even large vendors of programmable automation use engineers—"applications engineers"—for marketing and pre- and post-sale support services. This situation reflects not only the technology-intensive nature of PA products but also the fact that experienced engineers commonly move into sales, management, and other nonproduction positions. Such individuals are likely to be counted as engineers in occupational statistics.

Want-ads suggest that PA vendors, like other manufacturers of technical products, prefer sales representatives with technical college degrees, but will consider others with relevant experience. Similar preferences may exist for trainers. Predictably, selection criteria for sales managers also emphasize relevant experience. Relevant experience may include a background in sales or use of computer and business systems, or in manufacturing or PA sales.

Shift in Skills and Occupational Mix

As revealed by the preceding discussion of skill requirements and occupational trends, the proportions of skills and occupations found in manufacturing will shift substantially because of programmable automation. In fact, to date, this impact has been more striking than any change in the level of employment. While it is too soon to forecast precise numerical changes, the directions of change are clear. In some cases, the effect will be to reinforce the long-term shift toward white-collar employment; in other cases—notably, the negative effect on clerical opportunities—the long-term effect will differ from past shifts. This section describes the overall pattern of change in occupational mix and discusses the income implications of such change.

Shift Toward White Collar/ Salaried Employment

The broad—and long-term—tendencies are for employment opportunities of:

- engineers and computer scientists; technicians; and mechanics, repairers, and installers, on the whole, to rise—although specific occupations (e.g., drafters) will face diminishing opportunities;

- craftworkers (excluding mechanics), operatives, and laborers—especially the least skilled doing the most routine work—to **fall**;
- plant and perhaps other clerical personnel to **fall**; and
- managers and technical sales and service personnel to **rise**, although lower and middle management opportunities among users **may fall**.

Thus, a shift toward nonproduction or "white-collar" employment appears evident. Table 33 lists key occupations, 1980 employment levels, and the directions of potential change.*

Demonstrated Impact of Individual Technologies

Studies of the impacts of single automation technologies provide detailed evidence in support of a relative shift toward white-collar employment. For example, the Upjohn Institute forecast displacement, by 1990, of 100,000 to 200,000 production worker jobs due to robots alone, compared with creation of 10,000 to 20,000 jobs for maintaining robots and under 11,000 for robot applications engineering. Ayres and Miller of Carnegie-Mellon University forecast the potential displacement of 1 million to 4 million production worker jobs by robots, over a period of at least 20 years[60]

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*However, changes in the mix of occupations do not guarantee a rise in white-collar employment in all cases.

[60] Hunt and Hunt, op. cit.; and Robert U. Ayres and Steven M. Miller, "Robotics and Conservation of Human Resources," *Technology in Society*, vol. 9, 1982.

Table 33.—1980 Employment for All Manufacturing Industries, Selected PA-Sensitive Occupations

	Number	Percent	Long-term direction of change
Engineers	579,677	2.85	+
Electrical	173,647	0.85	+
Industrial	71,442	0.35	+
Mechanical	122,328	0.60	+
Engineering and science technicians	439,852	2.16	+
Drafters	116,423	0.57	–
NC tool programers	9,371	0.05	–
Computer programers	58,622	0.29	–
Computer systems analysts	42,404	0.21	+
Adult education teachers	5,165	0.03	+
Managers, officials, and proprietors	1,195,743	5.87	?
Clerical workers	2,297,379	11.28	–
Production clerks	139,947	0.69	–
Craft and related workers	3,768,395	18.51	–
Electricians	126,001	0.62	+
Maintenance mechanics and repairers	391,524	1.92	+
Machinists, tool and die makers	356,435	1.75	–
Inspectors and testers	538,275	2.64	–
Operatives	8,845,318	43.44	–
Assemblers	1,661,150	8.16	–
Metalworking operatives	1,470,169	7.22	–
Welders and flamecutters	400,629	1.97	–
Production painters	106,178	0.52	–
Industrial truck operators	269,105	1.32	–
Nonfarm laborers	1,576,576	7.74	–
Helpers, trades	100,752	0.49	–
Stockhandlers, order fillers	104,208	0.51	–
Work distributors	16,895	0.08	–
Conveyor operators	31,469	0.15	–

Note: Data refer only to wage and salary workers.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990 Alternatives," unpublished data.

(see table 34). And a German study found that when NC machine tools were introduced, the least skilled personnel (machine operators) were most likely to be laid off, while higher skilled programers, toolsetters, and mechanics were likely to be retained, and even more brought into the firm.[61]

A study of the effects of advanced telephone switching technologies showed that at Bell Canada, despite growth in output, technology limited growth in total man-hours of labor per year between 1952 and 1972 while producing large shifts in the occupational mix. The person-hour share of the least skilled category, operators, fell by over 20 percent while the shares of plant craftsmen and clerical personnel each rose by around 5 percent, and the "white-collar worker" share, least affected by technology change, rose by over 9 percent. The authors of that study concluded that new telecommunications technology outweighed change in labor costs as the cause of employment shifts, having the greatest effect on employment of the least skilled (and least expensive) workers.[62] **The pattern of large decline for the least skilled "production" workers and small increases among other categories is likely to occur with the introduction of programmable automation in manufacturing.**

Finally, similar trends emerge from a survey of workers in the Japanese electrical machine industry. It was reported that, when microelectronics was introduced into products or production processes, employment of "permanent workers" in machining, assembly, inspection, and quality control was likely to fall, while employment of production engineers was likely to rise or remain constant.[63]

Overall Effects

Occupational demand shifts stimulated by PA reinforce a long-term growth in the proportion of nonproduction workers employed in manufacturing industries. For example, between 1945 and 1979, the nonproduction worker proportion in the nonelectrical machinery industry rose from 24.2 to 34.4 percent. By comparison, the proportion for the highly automated chemicals and allied products industry rose from 22.5 to 42.8 percent in the same period. The trends within manufacturing are paralleled by trends within the economy as a whole; employment in craft, operative, and laborer positions overall is now about one-third of total employment.[64] The broad occupational shift reflects both technology change and the growth in nonmanufacturing employment: In 1940, there were 300 manufacturing jobs per 100 service industry jobs; in 1980 there were 113.[65]

Studies of the effects of microelectronics (and telecommunications) technologies on other economies show similar tendencies. For example, an OECD study drawing on research in several countries identified the following broad trends:

- within manufacturing industries, a decline in the proportion of production workers engaged in low-skill, rote activities such as assembly;
- within services, a decline in the proportion of more routine information-handling occupations (e.g., low-skilled clericals);
- within all sectors, a decline in the proportion of lower managerial and supervisory occupations, with remaining personnel

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[61] Werner Dostal and Klaus Kostner, "Changes in Employment With the Use of Numerically Controlled Machine Tools" (Mitteilungen aus der Arbeitsmarkt- und Berufsforschung), 1982.

[62] See Michael Denny and Melvyn Fuss, "The Effects of Factor Prices and Technological Changes on the Occupational Demand for Labor: Evidence From Canadian Telecommunications," *The Journal of Human Resources*, vol. 17, No. 2, 1983. The authors note that, "The force of automation can be seen from the fact that had technical change not occurred, the demand for operators would have increased over the 1952-72 period by 4 percent per annum rather than declining by 3 percent per annum. Similarly, zero output growth would have meant that the decline in operator demand would have increased to 7 percent per annum" (p. 175).

[63] Denki Roren, "Surveys on the Impacts of Micro-Electronics and Our Policies Towards Technological Innovation," paper presented at the 4th IMF World Conference for the Electrical and Electronics Industries, Oct. 3-5, 1983.

[64] U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings*, May 1983, p. 179.

[65] "Jobs in Nation's Service Industries Continue Rise in Recession: Set New Record, Top Manufacturing Total for First Time," *News*, U.S. Department of Labor, Bureau of Labor Statistics—Middle Atlantic Region, Dec. 8, 1982.

Table 34.—Carnegie-Mellon University Study Estimates

	Potential for robotization[a]									
	Level I robot		Level II		Operatives[b]		Potential displacement			
							Sector 34-37		Sector 33-38	
	Range percent	Average percent	Range percent	Average percent	Sector 34-37	Sector 33-38	I	II	I	II
Drill press/boring machine	25-50	30	60-75	65	104,050	113,210	31,215	68,933	33,963	73,587
Filer, grinder, buffer	5-35	20	5-75	35	77,360	103,430	15,472	27,076	2,086	36,201
Gearcutting, grinding, shaping		*10*		*50*	11,070	11,670	*1,107*	*5,535*	*1,167*	*5,835*
Grinding/abrading machine operator	10-20	18	20-100	50	97,090	109,680	17,476	48,545	19,742	54,840
Lathe/turning machine operator	10-20	18	40-60	50	130,260	141,560	23,447	65,130	25,481	70,780
Machine tool operator, combination	10-30	*15*	5-60	30	142,750	154,220	*21,413*	42,825	*23,133*	46,266
Machine tool operator, NC	10-90	20	30-90	49	41,900	45,020	8,380	20,531	9,004	22,060
Machine tool operator, toolroom	*1-5*	*3*	*4-60*	*50*	33,410	36,160	*1,002*	*16,705*	*1,085*	*18,080*
Machine tool operator, setter		*10*		*50*	47,260	51,490	*4,726*	*23,630*	*5,149*	*25,745*
Milling/planing machine operator	10-20	18	40-60	50	58,900	63,230	*10,602*	29,450	11,381	31,615
Sawyer, metal		*20*		*50*	10,660	15,180	*2,132*	*5,330*	*3,036*	*7,590*
Subtotal, metalcutting machines					**754,710**	**844,850**	**136,972**	**353,690**	**135,227**	**392,599**
Coil winding	15-40	24	15-50	40	26,570	33,550	6,377	10,628	8,052	13,420
Drop hammer operator		*15*		*70*	2,990	2,990	*449*	*2,093*	*449*	*2,093*
Forging press operator		*15*		*70*	6,500	7,190	*975*	*4,550*	*1,079*	*5,033*
Forging/straightening roll operator		*15*		*70*	1,000	2,840	*150*	*700*	*426*	*1,988*
Header operator		*20*		*70*	5,080	5,080	*1,016*	*3,556*	*1,016*	*3,556*
Power brake/bending machine		*20*		*70*	33,240	35,240	6,648	*23,268*	*7,004*	*24,514*
Press operator/plate print		*20*		*70*	4,230	4,230	*846*	*2,961*	*846*	*2,961*
Punch press operator	10-100	15	60-80	70	159,890	171,710	23,984	111,923	25,757	120,197
Punch press setter		*15*		*70*	16,080	16,840	*2,412*	*11,256*	*2,526*	*11,788*
Riveter (light)	5-100	15	10-100	30	9,090	9,090	1,364	2,727	1,364	2,727
Roll forming machine		*20*		*70*	4,320	11,030	*864*	*3,024*	*2,206*	*7,721*
Shearer/slitter operator		*20*		*70*	22,450	28,660	*4,490*	*15,715*	*5,732*	*20,062*
Subtotal, metalforming machines					**291,440**	**344,310**	**49,575**	**192,401**	**56,467**	**216,060**
Conveyor operator/tender		*10*		*30*	18,070	20,240	*1,807*	*5,421*	*2,024*	*6,072*
Die casting machine operator	5-15	5	10-20	10	6,530	14,670	327	653	734	1,467
Dip plater	20-100	40	50-100	77	7,780	9,500	3,112	5,991	3,800	7,315
Electroplater	5-40	20	5-60	55	27,350	29,770	5,470	15,043	7,954	16,374
Plater helper		*30*		*100*	26,100	26,560	*7,830*	*26,100*	*7,968*	*26,560*
Fabricator, metal		*10*		*30*	5,910	5,910	*591*	*1,773*	*591*	*1,773*
Fabricator, plastic		*10*		*30*	1,970	1,970	*197*	*591*	*197*	*591*
Furnace operator/cuppola tender		*20*		*50*	4,420	14,490	*884*	*2,210*	*2,898*	*7,245*
Heater, metal		*20*		*100*	2,070	5,010	*414*	*2,070*	*1,002*	*5,010*
Heat treater, annealer	5-50	10	5-90	46	14,770	23,440	1,477	6,794	2,344	10,782
Injection/compression mold operator (plastic)		*20*		*50*	24,910	29,830	*4,982*	*12,455*	*5,966*	*14,915*
Inspector	5-25	13	5-60	35	228,530	269,650	29,709	79,986	35,055	94,378
Laminator, preforms		*20*		*50*	10,160	10,160	*2,032*	*5,080*	*2,032*	*5,080*
Machine operator, n.e.c.[c]	10-50	16	20-65	25	13,020	38,590	2,083	3,255	6,174	9,648
Molder, machine		*20*		*50*	5,650	18,540	*1,130*	*2,825*	*3,708*	*9,270*
Packager, production	1-40	16	2-70	41	55,480	75,640	8,877	22,747	12,102	30,939
Painter, production	30-100	44	50-100	66	74,380	78,540	32,727	49,091	34,558	51,836
Pourer metal	5-20	10	10-30	24	1,280	13,280	128	307	1,328	3,187
Sandblaster, shotblaster	10-100	35	10-100	35	6,290	10,030	2,202	2,202	3,511	3,511
Screwdriver operator (power)		*10*		*50*	3,420	3,420	*342*	*1,710*	*342*	*1,710*
Tester	1-10	8	5-30	12	51,470	62,890	4,118	6,176	5,031	7,558
Wirer, electric	0-10	9	10-50	28	22,940	26,520	2,065	6,423	2,387	7,426
Subtotal, miscellaneous machines					**612,500**	**788,850**	**112,504**	**258,903**	**141,700**	**322,647**
Joining (welding)	10-60	27	10-90	49	319,040	344,280	86,141	156,330	92,956	168,697
Assembly	3-20	10	20-50	30	1,182,650	1,318,750	118,265	354,795	131,875	395,625
Total of subtotals + joining + assembly					**3,160,340**	**3,640,840**	**503,457**	**1,316,119**	**558,220**	**1,495,628**

[a] Time frame is uncertain; authors refer to "eventual" displacement potential.

[b] Employment figures are from Bureau of Labor Statistics, *Occupational Employment in Manufacturing Industries* (Washington, D.C.: U.S. Government Printing Office, 1977).

[c] n.e.c. = Not elsewhere classified.

NOTE: The italicized numbers are estimates by Robert U. Ayers, based on similarity.

SOURCE: *The Impacts of Robotics on the Workforce and Workplace*, Carnegie-Mellon University, June 1981.

more restricted to preparing and transmitting information to upper management;

- growth in the proportion of occupations installing, operating, and repairing new equipment and providing related support; and
- some deskilling of tasks in some craft occupations due to transfer of prior operator functions to machines.[66]

However, it is imprudent to simply take past trends as accurate forecasts of the future. For example, there are indications that the occupational shift is not inexorable, at least in the short term. Researchers at New York University, in the study cited at the beginning of this chapter, forecast the effects on labor demand in 1990 and 2000 of a growing use of computer technology in manufacturing, office, health-service, and education settings. They concluded that the overall trend toward white-collar employment would continue, but that the shift would be greater for the slower of two alternative trends for the diffusion of computer technologies.

Their analysis suggests that the large size of the investment in capital goods required for the diffusion of computer-based technologies could buoy manufacturing industry and production occupation employment throughout this century. While computerization reduces demand for labor overall, because of anticipated slow growth in labor supply it can serve to avert potential shortages of certain types of personnel rather than create unemployment. Although, like any other modeling exercise, that analysis is shaped by its underlying assumptions, it shows how output levels can determine employment mix as well as level. Thus, output levels, economic performance and growth can be seen to be vital to employment.

PA Producer Employment Mix

The emerging occupational mix found in automation producers may indicate future trends for the metalworking industries generally—and perhaps for the rest of the manufacturing sector as well. The Upjohn Institute, for example, suggested that two-thirds of the jobs among robot producers would be white-collar, including professionals, technicians, administrators, sales, and clerical workers.* Researchers at New York University, drawing on discussions with the leading robot producer (Unimation), also estimated that about two-thirds of employment in the robot industry would be white-collar, although it had different detailed estimates (see table 35). Finally, a similar appraisal was provided in recent congressional testimony by Walt Weisel, chief executive of a robot manufacturer (Prab Robots) and president of the Robotic Industries Association (formerly the Robot Institute of America). Weisel forecast new jobs in sales, applications engineering, research and development, and field service among producers, as well as new maintenance and manufacturing process jobs among users.** These examples reflect the fact that production work is relatively limited among producers of programmable automation (see ch. 7); its role is also declining among other manufacturers.***

The implications of the employment mix found among producers of automated equipment can be seen by contrasting the staffing profiles of the electronic and computing machinery and engineering and architectural services

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[66] OECD, *Information Activities, Electronics and Telecommunications Technologies*, Paris, 1981. An econometric study of the Canadian economy described in that OECD volume suggested that, as capital intensity grows, complexity of operations also grows, making planning and coordination—and associated personnel—more necessary. It also found that as the cost of capital or equipment falls relative to other costs, demand for "information labor" rises, while demand for "noninformation labor" falls.

*That study estimated that employment by domestic robot manufacturers was approximately 2,000 persons in 1982 and would grow to between 9,000 and 17,000 by 1990. Hunt and Hunt, op. cit.

**Testimony during hearings before the House Committee on Small Business, Subcommittee on General Oversight and the Economy, May 17, 1983.

***The Upjohn Institute also estimated that there would be about 8,000 to 16,000 jobs associated with supplying hardware components to robot producers by 1990. This latter estimate assumes domestic sourcing of hardware; it will overstate actual supplier employment potential if companies continue to expand their imports of robotic hardware.

Table 35.—Estimates of Robot Manufacturer Staffing Profiles, 1982

Occupation	Robot manufacturing (%)
New York University [a]	
Electrical engineers	12.1%
Industrial engineers	2.2
Mechanical engineers	4.4
Other engineers	8.3
Computer programers	2.1
Computer systems analysts	0.9
Other computer specialists	0.3
Personnel and labor relations workers	0.3
Other professional, technical	8.2
Managers, officials, proprietors	9.0
Sales workers	4.0
Stenographers, typists, secretaries	5.6
Office machine operators	0.9
Other clerical	9.2
Electricians	0.9
Foreman, n.e.c	0.8
Machinists	2.3
Other metalworking craftworkers	1.5
Mechanics, repairers	0.8
Assemblers	14.7
Checkers, examiners, inspectors	2.8
Packers and wrappers	0.4
Painters	0.7
Welders, flame cutters	0.9
Other operatives	5.6
Janitors and sextons	0.4
Laborers	0.7
Total	100.0

Occupation	Robot manufacturing (%)
Upjohn Institute [b]	
Engineers	23.7%
Engineering technicians	15.7
All other professional and technical workers	4.2
Managers, officials, proprietors	6.8
Sales workers	3.4
Clerical workers	13.9
Skilled craft and related workers	8.4
Semiskilled metalworking operatives	4.2
Assemblers and all other operatives	19.0
Service workers	—
Laborers	0.7
Farmers and farmworkers	—
Total	100.0

Columns may not add to total due to rounding.
n.e.c. = not elsewhere classified.

SOURCES: [a] Wassily Leontief and Faye Duchin, *The Impacts of Automation on Employment, 1963-2000,* final report. New York University, Institute for Economic Analysis, April 1984. Data based on staffing of Unimation, Inc. (now part of Westinghouse).
[b] H. Allan Hunt and Timothy L. Hunt, *Human Resource Implications of Robotics,* The W. E. Upjohn Institute for Employment Research, 1983.

industries with those of the motor vehicles and parts, metalworking machinery, and primary metals industries (see table 36). The electronic and computing machinery industries have primarily employed professional and technical workers (39 percent) and other white-collar personnel, as has the engineering and architectural services industry (69 percent professional and technical). By contrast, employment in the other industries has a more even distribution over a larger range of occupations, with many more opportunities in production jobs. For example, craft and kindred workers and operatives each comprise about a third of the employment in metalworking machinery; they have comprised 20 percent and over 50 percent, respectively, of motor vehicle employment.

The staffing contrast is instructive, because employment opportunities for producing PA will be more like those in the computer industry than in conventional metalworking manufacturing. As noted by the Upjohn Institute:

> The most remarkable thing about the job displacement and job creation impacts of industrial robots is not that more jobs are eliminated than created; this follows from the fact that robots are labor-saving technology designed to raise productivity and lower costs of production. Rather, it is the skill-twist that emerges so clearly when the jobs eliminated are compared to the jobs created . . . We submit that this is the true meaning of the so-called robotics revolution.[67]

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[67] Hunt and Hunt, op. cit., p. 172.

Table 36.—Industry Staffing Pattern Contrasts

	Metalworking machinery and equipment		Motor vehicles and parts		Office, computing, and accounting machinery		Computer and data-processing services		Engineering and architectural services	
Professional, technical, and related workers	32,617	8.8%	45,417	5.9%	139,922	32.5%	86,351	29.5%	349,063	62.7%
Managers, officials, and proprietors	28,190	7.6	25,424	3.3	40,583	9.4	37,244	12.7	58,947	10.6
Sales workers	7,207	1.9	3,837	0.5	4,107	1	9,965	3.4	2,345	0.4
Clerical workers	40,429	10.9	47,973	6.2	69,320	16.1	147,665	50.4	85,066	15.3
Craft and related workers	99,306	26.7	161,297	20.8	52,055	12.1	3,982	1.4	12,591	2.3
Operatives	146,706	39.5	520,413	54.3	112,377	26.1	5,242	1.8	41,557	7.5
Service workers	7,496	2	22,003	2.8	4,771	1.1	1,681	0.6	4,786	0.9
Nonfarm laborers	9,544	2.6	47,433	6.1	7,677	1.8	672	0.2	2,346	0.4

NOTE: Percentages have been rounded.

SOURCE: Bureau of Labor Statistics, "Employment by Industry and Occupation, 1980 and Projected 1990 Alternatives," unpublished data on wage and salary employment.

The contrast in staffing patterns implies that there will be relatively few opportunities for people to move easily from other metalworking manufacturing jobs into automation-producer jobs. It also implies that there may be fewer opportunities for promotion from production to nonproduction work.

Intercompany Patterns

Where automation is part of broader process changes that also include changes in business relations between manufacturers and their suppliers or distributors, occupational shifts within companies may mask offsetting or amplifying trends in related firms (upstream or downstream). Computer links between facilities, in particular, may affect facility staffing. Eaton, for example, is implementing a computer-aided design and manufacturing system that will share information about product design, process planning, materials requirements, and costs among computers at 200 Eaton manufacturing facilities (and many subcontractors). Such a network will reduce engineering and other personnel requirements per facility.[68]

As was discussed earlier, the spread of CAD and its integration with CAM may alter companies' decisions on whether to contract out for drafting and other design services. In addition, the growth of automation service and consulting firms will affect producer and user hiring of applications engineering staffs. While manufacturers have increasingly contracted out for "producer services" such as accounting, food services, and security, programmable automation may reinforce or counter this trend for individual services, thereby influencing staffing patterns among both manufacturing and service firms.

Transient Skill Requirements

One factor that cushions employment adjustment in the short term but presents challenges for long-term planning and adjustment is the tendency of early or simpler types of programmable automation (and other computer applications) to require work that is found to be no longer needed with more advanced technology. A classic example, in the case of computers, is keypunching. Keypunchers are still in demand in the United States (over 57,000 were employed in 1980) because many computer users cannot afford to jettison outmoded data-entry systems when improved technologies come along. The availability of new technology thus does not guarantee an immediate demand for new skills and staffing. However, keypunching was the only computer field to experience declining employment in the 1970's.

The most obvious areas in which skill requirements associated with PA may be short-lived, at least in some firms, are data entry, data transfer, and programing. One major aerospace user of PA, for example, anticipates a major reduction in its use of engineering and computer support personnel with the integration of various computer-based systems.[69] As early as 1977, NC users responding to a survey conducted by MIT researchers "reported a desire to reduce both programing and maintenance costs by increasing their dependence on computer sophistication and reducing the need for highly skilled technicians."[70]

At present, different automation equipment and systems have different programing and data-processing needs. Integration of those systems where applicable, development of a standard language, and/or other developments (see ch. 3) may bring about a sharp reduction in the amount of programing that is necessary. CAD, CAE, and computer-based management systems typically use commercial software packages and involve little programing by users. Although data entry is necessary to establish databases, after the initial input

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[68] *American Metal Market/Metalworking News*, May 16, 1983.

[69] OTA case study.

[70] Robert T. Lund and Christopher J. Barnett, "Numerically Controlled Machine Tools and Group Technology: A Study of U.S. Experience," MIT Center for Policy Alternatives, Jan. 13, 1978.

Photo credit: McDonnell Douglas Automation Co.

Graphics-based offline robot programing using a CAD system

stage updating may be handled by professionals using distributed, interactive systems.*

Robots are usually programed with easy-to-use software that generally does not require programing skills, and they have tended to be reprogramed infrequently. Moreover, direct links between robots and CAD or CAE systems will further reduce robot programing. Similarly, NC programing is becoming simpler, and direct links to CAD or CAE systems will reduce programing requirements. While users may develop greater needs for persons capable of adapting programs, they will have less need for program creators, although such persons may remain important to suppliers of PA equipment systems.

Transient jobs tend to persist among small firms longer than among larger ones, inasmuch as small firms are less able to adopt newer technology. However, the development of cheaper, smaller, easier-to-use PA systems —such as those currently fueling market growth for CAD and CNC, in particular—will hasten their adoption by smaller firms during this decade and the next (see ch. 7).*

Qualification Trends

Evidence from the United States and other countries suggests that, though automation is simplifying production tasks, employers are hiring better qualified, more skilled personnel. Insofar as this occurs, simple contrasts in occupational employment levels will not be accurate indicators of changes in skill requirements.

Research from Japan and West Germany brings out the contrast between employee qualifications and skill requirements:

- A Japanese survey reported that the spread of microelectronics was associated on the one hand with substantial growth in employment of high school and college graduates with science and engineering majors and on the other hand with growth in the number of machine operators doing simple or unskilled tasks.[71]
- A Japanese case study of automation in software development found that companies hired better educated staff over time but adopted automated techniques aimed

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*Computer-industry representatives see improved software and easier-to-use systems as a response to a perceived shortage of programers and other data-processing personnel. At an April 1983 conference, one software company spokesman contended, "What we need is to make microcomputers easy enough to use so that end users can control their destiny." See Robert Batt, "Micros Seen Holding Key to DPer Lack," *Computerworld*, Apr. 25, 1983.

*To put the timing issue into perspective, note that most job openings represent the replacement of personnel, rather than employment growth. Replacement hiring occurs not only because of deaths, retirements, and resignations, but also because people move between occupations as well as jobs. Replacement needs are one reason why BLS and others forecast that most 1980's job openings will occur in existing occupations, and that PA will have a negligible effect on many of the occupations expected to grow the most. Indeed, although 5 computer-related occupations experienced dramatic employment growth (ranging from 28 percent for data-entry personnel to 477 percent for other computer specialists) between 1972 and 1982, as a group they accounted for slightly more than 5 percent of overall job growth in that period. See Ronald E. Kutscher, testimony before the House Committee on Small Business, Subcommittee on Oversight and the Economy, hearings on "The Impact of Robots and Computers on the Workforce of the 1980's," May 18, 1983.

[71] "Ministry of Labor Report on Microelectronics and Its Impact on Labor," cable from American Embassy (Tokyo) to U.S. Secretary of State, August 1983.

at simplifying work, allowing employees to "supervise" automated processes. Work tasks were changed in response to shortages of experienced personnel.[72]

- A Japanese survey of electrical machinery industry workers reported that operators of microelectronics-equipped machines in machine shops (and to a lesser extent in assembly shops) perceived a need to understand computers, programing, electricity, and electronics, while machine "supervision" and monotonous routine work increased.[73]
- A West German study of the employment effects of NC machine tools reported that workers increasingly perceived a need for "professional training," while their responsibilities shifted from machine operation to machine "supervision."[74]

The preference of employers to hire (or retain) well-educated personnel, both in the United States and abroad, suggests that higher education or skill may be regarded as an indicator of other attributes such as responsibility (desired because of growing investments in equipment) or an ability to solve problems and troubleshoot (desired because of growing dependence on equipment and the costs of a breakdown). Thus, the Japanese survey of electrical machinery workers noted a need for "attitudes such as meticulousness and accuracy, the readiness to learn new things, and so forth" that allow prompt decisionmaking and quick responses.

In the short term, employers may continue to employ personnel who are on average more or less skilled than necessary. This is because most companies are inexperienced with programmable automation, especially the production technologies, and are not yet familiar with their exact skill requirements and capabilities. In the long term, as experience is gained, companies may employ more lower skilled people plus a few highly skilled people working at higher levels. This may come about because PA can lower skill requirements as well as job numbers at low and middle levels of organizations, and because companies generally try to reduce the amount of skill they have to pay for. On the other hand, companies try to avoid wholesale replacement of skilled categories, since skilled workers are generally more productive than others. The transition in skill mix is likely to be gradual, and it will vary among firms and industries.

Compensation Patterns

Occupational shifts affect wage levels and in turn influence the income distribution and the buying power of consumers. The shifts discussed in this chapter will alter wage patterns both within the manufacturing sector and between it and other sectors. While short-term trends can be identified, long-term implications are less clear; they depend on many factors besides technology change.

A major implication of the shift to "white-collar" or salaried jobs, given contemporary wage patterns, is a reduction in access to well-paying jobs for individuals with a high school education or less, individuals who have traditionally found ready employment in the manufacturing sector (and in production jobs in particular). In many cases, manufacturing personnel earn higher pay than their skill levels or educational attainment would suggest, in part because of collective bargaining. By contrast, many low-skill service jobs pay less and offer less job security, in part because of the absence of collective bargaining. Lack of proper education and training or employer prejudices, as well as a reduction in available job opportunities, may restrict the movement of such individuals into higher skilled jobs in the manufacturing sector, while technology change and import competition may reduce the total number of manufacturing jobs.*

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[72] Japan Labor Association, "A Special Study Concerning Technological Innovation and Labor-Management Relations," interim report, June 1983. Also, note that this experience is similar to conditions observed following the introduction of NC machine tools.

[73] Denki Roren, "Surveys on the Impacts of Micro-Electronics and Our Policies Toward Technological Innovation," paper presented at the 4th IMF World Conference for the Electrical and Electronics Industries, October 1983.

[74] Werner Dostal and Klaus Kostner, "Changes in Employment With the Use of Numerically Controlled Machine Tools," (Mitteilungen aus der Arbeitsmarkt- und Berufsforschung), 1982.

Figure 16 contrasts the earnings distribution for agriculture and industry and for services in 1971 and 1981. Lower levels of compensation for the service sector as a whole reflect the relative lack of unionization, the prevalence of small firms, the greater role of part-time work, and the predominance of women.** Table 37 shows the distribution of average earnings by industry; table 38 shows that average earnings in metalworking industries are higher than those in durable manufacturing overall; and table 39 shows earnings levels by occupation in machine tool industries.

As the above contrasts suggest, employees displaced from manufacturing employment may suffer reductions in earnings, income, and job security if they move into new jobs in service industries or into other jobs in manufacturing that are not subject to collective bargaining. The losses are especially likely for older workers, whose wages would have grown with seniority.

Changes in job mix may affect the distribution of income more than the level of income overall. In very general terms, PA and other factors will contribute to long-term growth in output and, therefore, aggregate income. While shifts in job mix may depress wage growth, returns on invested capital may grow, shifting spending power from workers to investors (many of whom are workers themselves). This shift may be compounded inasmuch as wage earners are more likely than investors to spend on relatively labor-intensive goods and services, as some evidence suggests.*

Past trends suggest that technological change and the declining share of manufacturing jobs in the economy have eroded midlevel job and income opportunities, polarizing the work force and income distribution (see table 40). Noyelle, for example, argues from an analysis of private sector earnings distributions that:

> Medium jobs are shrinking in importance across the economy, in good part because employers are increasingly emphasizing the concentration of skills in a relatively narrow stratum of upper level jobs, while dealing with the rest of their work force as a buffer that can be adjusted over the course of the economic cycle.[75]

However, it is not clear that this pattern will continue in the long run. While long-term changes in wage patterns and income distribution are beyond the scope of this report, several observations can be made here.

Stanback and Noyelle attribute the loss of midlevel jobs in manufacturing to "increased separation between production and administrative functions . . . and the increased division of the work process within both production and corporate administration."[76] Programmable automation should counteract these trends, because it aims to integrate production and administration. Also, PA may help to reduce employment fluctuations among firms in the future because it simultaneously lowers labor requirements and encourages broader job descriptions, which may make workers less "dispensable." Moreover, as suggested by the discussion of occupational trends above, PA may so blur occupational

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*A survey performed by Westat for OTA in August 1982 showed a propensity of firms—especially those that are relatively large or relatively heavy users of automation—to train professionals and high-skilled production workers to work with automated equipment.

**"A large share of the rapidly increasing service sector employment has involved work traditionally done by women at low pay, and throughout the period (1950-81) there has been a marked tendency for much of the new white-collar work to be defined as women's work, paid for at relatively low rates and performed by women and until recently by young workers from the baby-boom generation." Thomas M. Stanback, Jr., "Work Force Trends," *The Long-Term Impact of Technology on Employment and Unemployment* (Washington, D.C.: National Academy Press, 1983).

*Note that between 1968 and 1982, personal consumption expenditures consistently grew faster than GNP; consumer spending is the largest component of GNP. See Arthur J. Andreassen, "Economic Outlook for the 1990's: Three Scenarios for Economic Growth," *Monthly Labor Review*, November 1983.

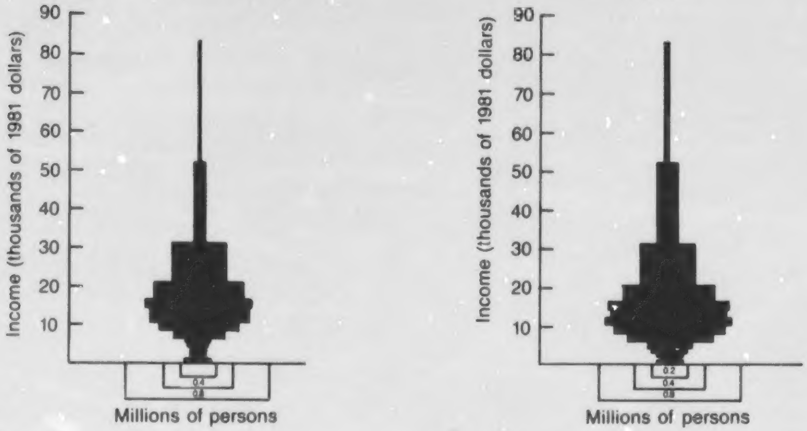
[75] Thierry J. Noyelle, "People, Cities, and Services," *The Entrepreneurial Economy*, June 1983.

[76] Thomas N. Stanback, Jr., and Thierry J. Noyelle, *Cities in Transition* (Totowa, N.J.: Allanheld, Osmun & Co., 1982).

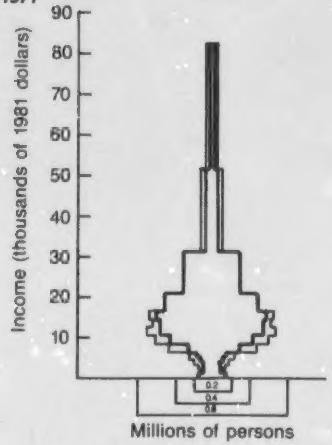
Figure 16.—Sectoral Earnings Patterns

Distribution of income for full-time workers in agriculture and industry and in the service sector, 1971

Agriculture and industry sector *Service sector*

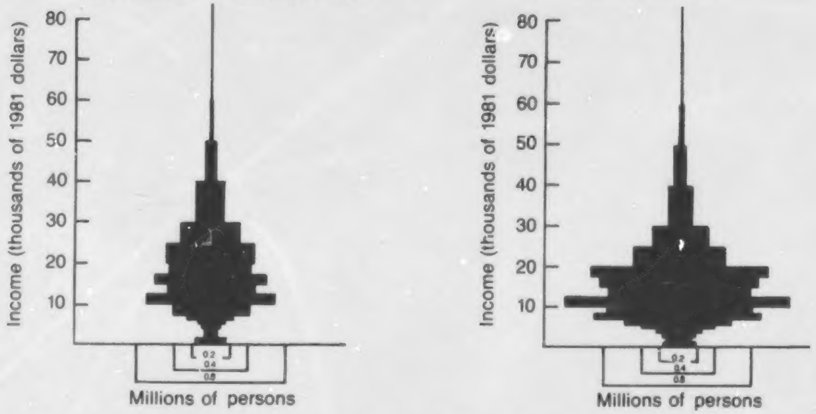


Superimposition of income distribution of agricultural and industrial workers on income distribution of service workers, 1971

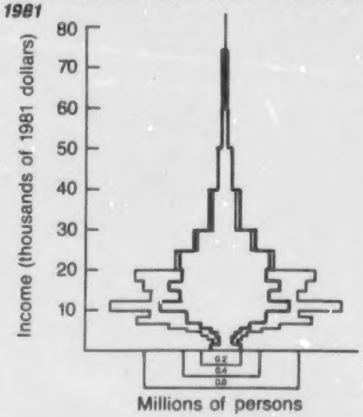


Distribution of income for full-time workers in agriculture and industry and in the service sector, 1981

Agriculture and industry sector *Service sector*



Superimposition of income distribution of agricultural and industrial workers on income distribution of service workers, 1981



SOURCE: John S. Reed, "Employment and Unemployment in the Service Sector," *The Long-Term Impact of Technology on Employment and Unemployment* (Washington, D.C.: National Academy Press, 1983).

Table 37.—Earnings by Industry (gross hours and earnings of production or nonsupervisory workers[a] on private nonagricultural payrolls by industry division and major manufacturing group)

Industry	Average weekly hours				Average hourly earnings				Average weekly earnings			
	1979	1980	1981	1982	1979	1980	1981	1982	1979	1980	1981	1982
Total private	35.7	35.3	35.2	34.8	$6.16	$6.66	$ 7.25	$ 7.67	$219.91	$235.10	$255.20	$266.92
Mining	43.0	43.3	43.7	42.6	8.49	9.17	10.04	0.83	365.07	397.06	438.75	459.23
Construction	37.0	37.0	36.9	36.7	9.27	9.94	10.82	1.55	342.99	367.78	399.26	426.45
Manufacturing	40.2	39.7	39.8	38.9	6.70	7.27	7.99	8.50	269.34	288.62	318.00	330.65
Overtime hours	3.3	2.8	2.8	2.3	—	—	—	—	—	—	—	—
Durable goods	40.8	40.1	40.2	39.3	7.13	7.75	8.54	9.05	290.90	310.78	343.31	355.06
Overtime hours	3.5	2.8	2.8	2.2	—	—	—	—	—	—	—	—
Lumber and wood products	39.4	38.5	38.7	38.0	6.07	6.55	6.99	7.50	239.16	252.18	270.51	283.48
Furniture and fixtures	38.7	38.1	38.4	37.2	5.06	5.49	5.91	6.33	195.82	209.17	226.94	234.73
Stone, clay, and glass products	41.5	40.8	40.6	40.0	6.85	7.50	8.27	8.87	284.28	306.00	335.76	354.40
Primary metal industries	41.4	40.1	40.5	38.6	8.98	9.77	10.81	11.34	371.77	391.78	437.81	437.34
Fabricated metal products	40.7	40.4	40.3	39.2	6.85	7.45	8.19	8.78	278.80	300.98	330.06	344.18
Machinery except electrical	41.8	41.0	40.9	39.7	7.32	8.00	8.81	9.28	305.98	328.00	360.33	368.81
Electric and electronic equipment	40.3	39.8	40.0	39.3	6.32	6.94	7.62	8.17	254.70	276.21	304.80	322.65
Transportation equipment	41.1	40.6	40.9	40.5	8.53	9.35	10.39	1.12	350.58	379.61	424.95	450.36
Instruments and related products	40.8	40.5	40.4	39.8	6.17	6.80	7.42	8.26	251.74	275.40	299.77	322.38
Miscellaneous manufacturing industries	38.8	38.7	38.8	38.5	5.03	5.46	5.97	6.41	195.16	211.30	231.64	247.56
Nondurable goods	39.3	39.0	39.1	38.4	6.01	6.55	7.18	7.73	236.19	255.45	280.74	296.83
Overtime hours	3.1	2.8	2.8	2.5	—	—	—	—	—	—	—	—
Food and kindred products	39.9	39.7	39.7	39.4	6.27	6.85	7.44	7.89	250.17	271.95	295.37	310.87
Tobacco manufactures	38.0	38.1	38.8	37.8	6.67	7.74	8.88	9.82	253.46	294.89	344.54	369.68
Textile mill products	40.4	40.1	39.6	37.5	4.66	5.07	5.52	5.83	188.26	203.31	218.59	218.63
Apparel and other textile products	35.3	35.4	35.7	34.7	4.23	4.56	4.97	5.18	149.32	161.42	177.43	180.44
Paper and allied products	42.6	42.2	42.5	41.8	7.13	7.84	8.60	9.32	303.74	330.85	365.50	389.58
Printing and publishing	37.5	37.1	37.3	37.1	6.94	7.53	8.19	8.73	260.25	279.36	305.49	324.63
Chemicals and allied products	41.9	41.5	41.6	40.9	7.60	8.30	9.12	9.98	318.44	344.45	379.39	407.36
Petroleum and coal products	43.8	41.8	43.2	43.9	9.36	0.10	11.38	2.47	409.97	422.18	491.62	546.99
Rubber and miscellaneous plastics products	40.5	40.0	40.3	39.6	5.97	6.52	7.17	7.63	241.79	260.80	288.95	302.94
Leather and leather products	36.5	36.7	36.7	35.6	4.22	4.58	4.99	5.33	154.03	168.09	183.13	189.39
Transportation and public utilities	39.9	39.6	39.4	39.0	8.16	8.87	9.70	0.30	325.58	351.25	382.18	401.70
Wholesale and retail trade	32.6	32.2	32.2	31.9	5.06	5.48	5.92	6.22	164.96	176.46	190.62	198.10
Wholesale trade	38.8	38.5	38.5	38.4	6.39	6.96	7.56	8.06	247.93	267.96	291.06	309.97
Retail trade	30.6	30.2	30.1	29.9	4.53	4.88	5.25	5.49	138.62	147.38	158.03	163.55
Finance, insurance, and real estate	36.2	36.2	36.3	36.2	5.27	5.79	6.31	6.79	190.77	209.60	229.05	245.44
Services	32.7	32.6	32.6	32.6	5.36	5.85	6.41	6.90	175.27	190.71	208.97	224.94

[a] Data relate to production and related workers in mining and manufacturing; to construction workers in construction; and to nonsupervisory workers in transportation and public utilities; wholesale and retail trade; finance, insurance, and real estate; and services.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, *Employment & Earnings*, 1984, establishment data, annual averages.

Table 38.—Earnings of Production Workers, Selected Industry Groups, 1936 to Date, Annual Averages

Year	Durable goods industries	Nonelectrical machinery industry	Motor vehicles & equipment industry	Aircraft and parts industry	Metal-working machinery industry	Metal-cutting machinery industry
Average weekly						
1936	$ 23.72	NA	$ 30.13	NA	NA	$ 28.73
1937	26.61	NA	32.66	NA	NA	32.48
1938	23.70	NA	30.59	NA	NA	26.75
1939	26.19	NA	33.58	NA	NA	32.34
1940	28.07	NA	36.69	NA	NA	37.44
1941	33.56	NA	42.68	NA	NA	44.22
1942	42.17	NA	54.15	NA	NA	52.70
1943	48.73	NA	59.13	NA	NA	55.11
1944	51.38	NA	60.12	NA	NA	58.19
1945	48.36	NA	55.28	NA	NA	57.14
1946	46.22	NA	52.28	NA	NA	54.40
1947	51.76	$ 57.58	58.63	$ 54.74	$ 58.69	57.87
1948	56.36	60.38	63.15	60.97	63.13	61.68
1949	57.25	60.31	67.33	63.34	61.33	59.23
1950	62.43	67.08	74.85	68.10	71.73	69.87
1951	68.48	76.13	77.16	77.96	86.01	85.14
1952	72.63	79.55	84.87	81.27	92.20	90.24
1953	76.63	82.68	89.88	83.38	96.81	95.17
1954	76.19	81.40	91.30	84.66	93.09	89.25
1955	82.19	87.36	99.84	89.21	98.34	95.48
1956	85.28	93.06	96.82	95.57	108.96	106.25
1957	88.26	94.12	100.61	96.35	106.89	101.04
1958	89.27	94.33	101.24	101.25	102.00	91.20
1959	96.05	102.92	111.38	106.63	113.74	106.93
1960	97.44	104.55	115.21	110.43	117.27	110.99
1961	100.35	107.42	114.65	114.68	117.04	111.92
1962	104.70	113.01	127.67	119.97	125.57	119.41
1963	108.09	116.20	132.68	122.43	128.90	124.42
1964	112.19	121.69	138.03	125.03	137.06	132.01
1965	117.18	127.58	147.63	131.88	144.37	138.76
1966	122.09	135.34	147.23	143.32	153.72	150.20
1967	123.60	135.89	144.84	146.97	154.56	154.25
1968	132.07	141.88	167.66	152.04	158.70	152.65
1969	139.59	152.15	170.56	161.35	172.38	166.61
1970	143.47	154.95	170.47	168.92	174.28	166.00
1971	153.52	161.99	195.29	175.82	174.62	163.90
1972	167.27	179.34	219.22	193.44	198.29	194.71
1973	179.28	193.83	237.08	207.50	214.90	219.11
1974	190.48	207.62	239.54	218.70	225.33	232.74
1975	205.09	219.22	262.68	246.19	226.46	232.68
1976	225.33	236.74	305.30	263.16	248.89	249.96
1977	248.46	259.79	345.40	289.95	279.72	290.18
1978	270.44	285.44	368.05	318.19	308.88	322.56
1979	290.90	305.98	372.37	351.05	329.30	344.21
1980	310.78	328.00	394.00	389.76	346.83	366.21
1981	342.91	360.33	450.31	425.80	371.49	383.95
1982	355.67	367.49	469.80	462.38	377.94	380.83

NA—Not Available

SOURCE: U.S. Bureau of Labor Statistics, "Employment and Earnings Statistics, 1909-70" (also monthly). National Machine Tool Builders' Association, *1983-1984 Economic Handbook of the Machine Tool Industry*.

Table 38.—Earnings of Production Workers, Selected Industry Groups, 1936 to Date, Annual Averages—Continued

Year	Durable goods industries	Nonelectrical machinery industry	Motor vehicles & equipment industry	Aircraft and parts industry	Metal-working machinery industry	Metal-cutting machinery industry
Average hourly						
1936	$ 0.58	NA	$ 0.76	NA	NA	$ 0.65
1937	0.67	NA	0.88	NA	NA	0.73
1938	0.68	NA	0.91	NA	NA	0.74
1939	0.69	NA	0.92	NA	NA	0.76
1940	0.72	NA	0.94	NA	NA	0.78
1941	0.80	NA	1.04	NA	NA	0.86
1942	0.94	NA	1.17	NA	NA	0.99
1943	1.05	NA	1.24	NA	NA	1.09
1944	1.11	NA	1.27	NA	NA	1.15
1945	1.10	NA	1.27	NA	NA	1.19
1946	1.14	NA	1.35	NA	NA	1.27
1947	1.28	$ 1.34	1.47	$ 1.37	$ 1.38	1.37
1948	1.40	1.46	1.61	1.49	1.49	1.47
1949	1.45	1.52	1.70	1.56	1.54	1.51
1950	1.52	1.60	1.78	1.64	1.65	1.62
1951	1.65	1.75	1.91	1.78	1.83	1.80
1952	1.75	1.85	2.05	1.89	1.97	1.92
1953	1.86	1.95	2.14	1.99	2.10	2.06
1954	1.90	2.00	2.20	2.07	2.17	2.10
1955	1.99	2.08	2.29	2.16	2.24	2.19
1956	2.08	2.20	2.35	2.27	2.40	2.33
1957	2.19	2.29	2.46	2.35	2.48	2.40
1958	2.26	2.37	2.55	2.50	2.55	2.40
1959	2.36	2.48	2.71	2.62	2.67	2.54
1960	2.43	2.55	2.81	2.70	2.74	2.63
1961	2.49	2.62	2.86	2.77	2.80	2.71
1962	2.56	2.71	2.99	2.87	2.90	2.79
1963	2.63	2.78	3.10	2.95	2.97	2.88
1964	2.71	2.87	3.21	3.02	3.08	2.98
1965	2.79	2.96	3.34	3.14	3.18	3.07
1966	2.90	3.09	3.44	3.31	3.32	3.23
1967	3.00	3.19	3.55	3.45	3.45	3.39
1968	3.19	3.37	3.89	3.62	3.64	3.55
1969	3.38	3.58	4.10	3.86	3.90	3.83
1970	3.56	3.77	4.23	4.12	4.12	4.00
1971	3.80	3.99	4.74	4.32	4.28	4.16
1972	4.05	4.27	5.11	4.65	4.59	4.56
1973	4.32	4.55	5.45	5.00	4.84	4.88
1974	4.68	4.92	5.90	5.40	5.18	5.23
1975	5.14	5.36	6.47	5.99	5.51	5.54
1976	5.55	5.76	7.10	6.45	5.94	5.98
1977	6.06	6.26	7.85	6.92	6.49	6.61
1978	6.58	6.78	8.50	7.54	7.02	7.20
1979	7.13	7.32	9.06	8.26	7.57	7.77
1980	7.75	8.00	9.85	9.28	8.18	8.38
1981	8.53	8.81	11.01	10.31	8.93	9.12
1982	9.05	9.28	11.60	11.25	9.52	9.79

NA—Not Available

SOURCE U S Bureau of Labor Statistics, "Employment and Earnings Statistics, 1909-70" (also monthly), National Machine Tool Builders' Association, *1983-1984 Economic Handbook of the Machine Tool Industry*

Table 39.—Average Hourly Earnings in the Machinery Manufacturing Industry,[a] in Selected Areas by Occupation, 1974-75, 1978, 1981

Region and survey year	Occupation					Occupation					
	Machine tool operators, production					Assemblers		Inspectors			
	Class A[b]	Class B[c]	Class C[d]	Numerically controlled	Tool room one type machine	Class A[f]	Class B[g]	Class A[h]	Class B[i]	Laborers, material handling	Tool clerks
1. Baltimore, Md.											
Winter 1974-75	$ 5.17	$4.60	$3.97	$ 5.06	$ 5.21[e]	$4.86	$4.39	$ 5.46	NA	$3.67	$4.07
January 1978	6.74	5.79	5.24	5.67	6.54[e]	6.03	5.71	6.72	NA	5.13	5.38
January 1981	9.01	7.84	7.01	7.68	NA	8.00	6.88	8.88	$7.72	7.21	NA
2. Boston, Mass											
Winter 1974-75	5.04	4.15	3.58	4.66	5.76	4.86	3.97	4.97	4.32	3.66	4.52
January 1978	6.54	6.01	4.71	6.24	6.72	6.18	4.89	NA	5.26	4.56	5.73
January 1981	8.59	8.35	5.87	8.44	NA	8.31	6.62	8.47	7.44	6.18	7.22
3. Buffalo, N.Y.											
Winter 1974-75	5.16	4.78	4.19	5.56	5.43	5.29	4.73	5.54	5.04	4.36	4.43
January 1978	6.77	6.28	5.44	7.00	6.80	6.92	6.43	7.20	6.36	NA	5.86
January 1981	8.97	8.25	7.01	9.47	7.74	9.24	8.07	9.35	7.62	8.11	7.80
4. Chicago, Ill.											
Winter 1974-75	5.71	5.02	4.49	5.59	6.20	5.35	4.58	5.51	5.15	4.30	4.68
January 1978	7.38	6.51	5.90	7.55	8.36	6.84	6.49	7.43	6.80	5.86	6.47
January 1981	9.60	8.00	6.63	9.51	11.31	8.95	7.43	9.25	8.56	6.81	9.10
5. Cleveland, Ohio											
Winter 1974-75	5.68	4.75	3.84	5.68	5.80	5.57	4.95	5.60	5.26	4.49	4.96
January 1978	7.02	6.01	4.12	7.17	7.09	7.21	6.13	7.20	6.65	6.07	6.50
January 1981	9.43	8.13	6.78	9.37	9.66	9.64	7.80	9.93	8.46	8.90	8.86
6. Denver, Colo.											
Winter 1974-75	5.53	4.43	3.78	5.34	5.84[e]	4.90	3.81	5.14	4.03	3.58	4.38
January 1978	6.60	5.36	5.04	6.44	6.63	5.94	4.30	6.67	5.93	4.75	5.89
January 1981	9.30	7.23	NA	8.28	10.69	7.79	5.40	8.55	7.04	5.89	7.54
7. Detroit, Mich.											
Winter 1974-75	6.07	5.46	4.42	6.29	6.68	6.15	5.60	5.74	5.65	4.79	5.44
January 1978	8.19	7.01	5.48	7.14	8.94	7.80	7.23	7.79	6.50	6.94	7.13
January 1981	11.61	9.48	6.21	9.44	12.08	11.17	9.59	11.01	NA	9.45	9.80
8. Houston, Tex.											
Winter 1974-75	5.40	5.01	3.91	5.50	5.31	5.27	4.47	5.43	4.60	4.21	4.65
January 1978	7.15	6.66	4.89	7.29	7.26	6.89	5.86	7.37	6.43	5.38	6.36
January 1981	9.92	NA	5.93	10.08	10.08	9.75	9.06	10.07	8.45	7.41	7.80
9. L.A.-Long Beach, Calif.											
Winter 1974-75	5.28	4.56	3.60	5.43	6.17	4.71	3.88	5.38	4.30	3.82	4.58
January 1978	6.87	5.45	3.96	6.86	7.44	6.29	4.41	6.47	5.50	4.67	5.24
January 1981	9.38	7.39	4.83	9.28	9.87	8.02	6.09	9.77	7.20	5.74	6.93
10. Milwaukee, Wis.											
Winter 1974-75	5.75	5.48	5.49	5.48	5.89	5.68	5.24	5.64	5.40	NA	4.77
January 1978	7.78	6.89	NA	7.43	7.86	7.72	6.96	7.24	6.97	6.19	6.28
January 1981	10.47	9.91	8.45	10.36	11.35	10.31	9.09	9.99	NA	8.88	9.13

Table 39.—Average Hourly Earnings in the Machinery Manufacturing Industry,[a] in Selected Areas by Occupation, 1974-75, 1978, 1981—Continued

	Occupation					Occupation					
	Machine tool operators, production					Assemblers		Inspectors			
Region and survey year	Class A[b]	Class B[c]	Class C[d]	Numerically controlled	Tool room one type machine	Class A[f]	Class B[g]	Class A[h]	Class B[i]	Laborers, material handling	Tool clerks
11. Newark, N.J.											
Winter 1974-75	5.31	5.31	3.86	5.61	5.71	5.28	4.21	4.87	4.92	4.02	4.85
January 1978	6.50	6.59	4.85	6.29	7.47	6.54	5.71	5.95	6.61	4.96	5.74
January 1981	9.44	9.04	6.35	7.68	NA	7.93	5.90	7.83	7.77	7.21	6.60
12. Pittsburgh, Pa.											
Winter 1974-75	5.55	5.36	4.97	5.19	5.43	5.80	4.48	6.19	4.99	4.17	4.65
January 1978	7.15	6.71	6.15	6.69	7.21[e]	7.14	6.02	7.37	6.66	5.33	6.18
January 1981	9.44	8.80	8.14	9.33	NA	8.52	7.78	9.44	8.79	8.74	7.48
13. St. Louis, Mo.-Ill.											
Winter 1974-75	6.54	5.07	4.69	6.33	5.76	5.78	4.70	6.23	5.03	4.17	4.62
January 1978	8.25	6.14	6.12	7.26	8.03	6.91	5.81	7.24	6.23	5.11	5.81
January 1981	9.45	8.36	8.30	9.27	8.69	9.10	7.57	9.04	8.35	6.79	7.86

NA-Not Available.

[a] Nonelectrical Machinery (SIC 35)

[b] Operators who set up their own machines and perform a variety of machine operations to close tolerances using decisions based on blueprints and layouts.

[c] Operators who set up their own machines and maintain operation set-ups made by others.

[d] Operators who perform routine and repetitive operations but do not set up machines.

[e] More than one type of machine.

[f] Fits and adjusts parts and makes decisions regarding proper performance of component or unit.

[g] Assembles parts in accordance with standard and prescribed procedures. Requires some fitting and adjusting.

[h] Responsible for decisions regarding quality of product and operations. Troubleshooting and interpreting of drawings and specifications is involved.

[i] Tests products and processes having rigid specifications with established inspection procedures.

SOURCE: Data from U.S. Department of Labor, Bureau of Labor Statistics, compiled in National Machine Tool Builders Association, *1983-1984 Economic Handbook of the Machine Tool Industry.*

Table 40.—Distribution of Total U.S. Labor Force Among Earnings Classes, 1960 and 1975, and Distribution of 1960-75 Job Increases in the Services

	Distribution of total U.S. labor force (percentages)[a]				1960-1975 job increases in services[b]		
Earnings classes[c]	1960		1975		Numbers of jobs (1,000)	Percentage	
1.60 and above	10.9	31.6	12.0	34.2	1,947	9.5	35.0
1.59 to 1.20	20.7		22.2		5,224	25.5	
1.19 to 0.80	35.9		27.8		2,311	11.3	
0.79 to 0.40	24.1	32.5	28.4	38.0	9,205	44.9	53.8
0.39 and below	8.4		9.6		1,829	8.9	
Total	100.0		100.0		20,516	100.0	

[a] Excludes agriculture, mining, and public administration.

[b] Transportation and other utilities, wholesale, retail, finance, insurance, real estate, corporate services, consumer services, and nonprofit.

[c] Relative to 1.0, for average earnings.

SOURCE: Thomas M. Stanback, Jr., "Work Force Trends," *The Long-Term Impact of Technology on Employment and Unemployment* (Washington, D.C.: National Academy Press, 1983).

distinctions (e.g., between engineer and technician in some cases) as to raise questions about equal pay for equal work, potentially motivating a compression of the pay scale.

Finally, the factors that shaped past patterns of service sector employment and compensation, such as an accelerating influx of women into the labor force, will not be the ones to shape future traits, especially if capital intensity and productivity grow in the service sector as expected (due to computerization and other factors) and as slower growth in the labor force makes labor scarcer (see below).

Nevertheless, the technologies may also allow a continuing polarization of the work force in at least some instances. For example, a recent study of software production found that individual workers are assigned small pieces of a larger task, which in turn is part of still larger tasks.

The elaborate division of labor energy in software work is sometimes—and mistakenly—called specialization. It is more accurately called fragmentation. Increasingly, software work is characterized by a stratification of responsibility and pay, not just a division of labor. What is unclear is whether there is a direct path between low-paying and high-paying positions.[77]

A common response, especially from the labor movement, to the prospect of a worsening income distribution (or erosion of earning power) due to changing job opportunities is to propose that work hours be reduced.[78] As Wassily Leontief has noted,

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[77] Philip Kraft and Steven Dubnoff, "Software Workers Survey," *Computer World* (in depth), Nov. 14, 1983.

[78] See, for example: AFL-CIO, "The Future of Work," mimeo 1983.

> The reduction of the average work week in manufacturing from 67 hours in 1870 to somewhat less than 42 hours must also be recognized as the withdrawal of many millions of working hours from the labor market. Since the end of World War II, however, the work week has remained almost constant.[79]

Moreover, jobs in manufacturing, especially among metalworking industries, typically include overtime hours of work (and corresponding extra pay). The United Automobile Workers Union has begun to press for reductions in overtime work as a means of increasing auto-industry employment. Its leadership has linked the issues of work hours, job security, and acceptance of technological change.[80] While reducing work hours can increase the number of jobholders, it may not be possible to employ more people without reducing real (i.e., adjusted for inflation) per-person wages. For this reason, job-sharing programs undertaken in Europe and in this country, including reductions in hours of work, have tended to be temporary.

Automation may allow real wages to increase only under certain circumstances, and where they do increase they may not increase enough (see fig. 17).* Increases in nominal as well as real wages will be constrained by increasing international competition. (Note that manufacturing workers in Hong Kong, as in other developing regions, work 6 days a week, 10 hours a day, have few holidays a year and earn relatively low wages. Their lower standard of living constrains us from raising ours where our products compete in the same market.) General Motors, for example, has attempted to increase its ability to compete with producers operating in low-wage countries by introducing a dual pay system which provides lower wages for new workers, confronting existing personnel with "an agonizing choice between going against deeply held union principles and giving some of their neighbors a chance for a job."[81] Several other companies have also moved to adopt dual pay systems, but such systems are considered controversial.[82] Other mechanisms for sharing work, such as early retirement (which shares jobs between generations rather than among contemporaries), may more easily preserve wage levels, although they may draw on a smaller pool of workers.

Profit-sharing may provide a means by which employees gain job security in exchange for variable compensation. Interest in profit-sharing has been growing recently. Both heightened international competition and greater capital intensity due to PA use may stimulate manufacturers' interest in profit-sharing.

Contextual Factors

There are many ways for companies to adjust to changing labor needs. Employers can lower their use of labor without layoffs or other involuntary separations of employees if: 1) the timing of displacement is paced according to the normal turnover or attrition rate of

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[79] Wassily W. Leontief, "The Distribution of Work and Income," *Scientific American*, September 1982. The average of weekly hours in manufacturing during 1982 was 38.9 (down from 40.2 in 1979), compared to 35.1 (down from 35.7 in 1979) for the total private nonfarm economy. See Valerie A. Personick, "The Job Outlook Through 1995: Industry Output and Employment Projections," *Monthly Labor Review*, November 1983; and U.S. Department of Labor, Bureau of Labor Statistics, Employment and Earnings, May 1983.

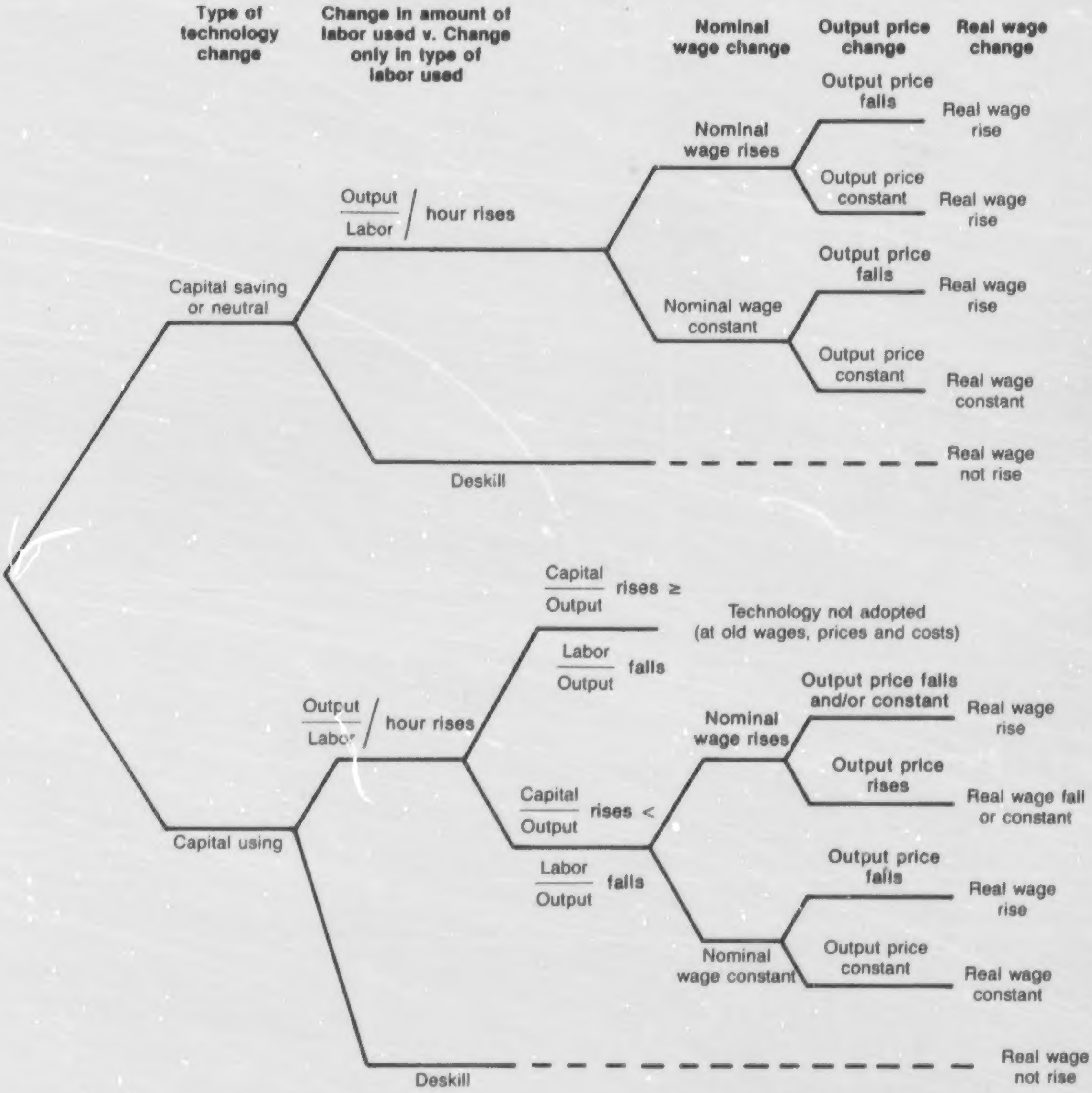
[80] "Overtime, Technology, '84, Issues" *Automotive News*, Dec. 19, 1983.

*Note that Leontief has argued that real wages are not likely to rise sufficiently to allow voluntary reductions in the work week, given anticipated technological displacement. Leontief advocates government intervention via income maintenance and income distribution programs. See Wassily N. Leontif, "The Distribution of Work and Income," op. cit.

[81] John Holusha, "G.M. Division Votes on Two-Level Pay," *The New York Times*, Aug. 24, 1983.

[82] Steven Flax, "Pay Cuts Before the Job Even Starts," *Fortune*, Jan. 9, 1984.

Figure 17.—Technology Change and Real Wages


Type of technology change
Change in amount of labor used v. Change only in type of labor used
Nominal wage change
Output price change
Real wage change
Capital saving or neutral
Output / Labor / hour rises
Nominal wage rises
Output price falls
Real wage rise
Output price constant
Real wage rise
Nominal wage constant
Output price falls
Real wage rise
Output price constant
Real wage constant
Deskill
Real wage not rise
Capital using
Output / Labor / hour rises
Capital / Output rises ≥ Labor / Output falls
Technology not adopted (at old wages, prices and costs)
Capital / Output rises < Labor / Output falls
Nominal wage rises
Output price falls and/or constant
Real wage rise
Output price rises
Real wage fall or constant
Nominal wage constant
Output price falls
Real wage rise
Output price constant
Real wage constant
Deskill
Real wage not rise

KEY: Deskill = Reduce % hi-skill, hi-wage

NOTE: There is no straightforward economic analysis of effect of change in skill mix as there is for change in labor productivity, per se.

SOURCE: OTA, based on analysis by Eileen Appelbaum, Temple University.

the firm (which reflects resignations, permanent disability departures, deaths, retirements, entry into extended military service, disciplinary discharges, and transfers); 2) current employees who wish to remain with the firm can do new work or jobs (on their own or with training); and/or 3) the level of output expands to at least accommodate the existing labor force, despite growth in output per employee.

AT&T, for example, increased automation without major layoffs during the 1950's and 1960's because of expanding output; it now appears to have less capacity for maintaining employment levels. General Electric, for example, is spending $100 million to modernize refrigerator production and expects to eliminate 1,000 jobs from that operation by the mid-1980's. However, it does not plan to lay off personnel because about 300 employees leave voluntarily each year, and the company plans to reassign personnel to other appliance-manufacturing jobs.[83] [84] Similarly, Westinghouse has a policy of not laying off personnel because of technology change.

This section examines relevant changes in the labor supply that may complement the effects of technology and demand changes on hiring patterns, and it examines Japanese approaches to work force adjustment. Chapter 6 discusses retraining and counseling programs to ease transitions of current employees.

Labor Supply

The makeup of the population and the labor force are important factors for evaluating the overall challenge of adjusting to changing job opportunities. The size, growth, and age structure of the labor force are relevant, as is composition by race and sex. OTA expects that some of the labor supply trends discussed below will help to offset the potential negative effects of PA on employment levels.

The total U.S. population is growing relatively slowly; the Census Bureau predicts that the population will reach its maximum size (308.9 million) in the year 2050. Growth in the labor force, which includes principally people between the ages of 16 and 65, peaked during the late 1970's following the influx of the baby-boom generation and rapid growth in labor force activity among women. The median age of the population has risen to over 30, and the proportion of the population under 25 is declining (it is now about 41 percent, down from 46 percent in 1970).[85] The number of persons aged 26 to 29 will also decline through this century. The median age of the labor force is almost 35, and the number and proportion of workers aged 16 to 24—the new entrant group—will fall. Consequently, the labor force is expected to grow relatively slowly in this and future decades (see tables 41 and 42).

Slower growth in the labor force makes the economy better able to absorb increases in output per worker without growth in unemployment. Indeed, for output to grow relative to the labor force, increases in output per worker would be necessary; without them, companies would experience labor shortages. On the other hand, if output does not grow fast enough relative to the labor force, labor surpluses may arise. Labor surpluses may be realized as unemployment, withdrawal from the labor force, or involuntary part-time employment and other forms of underemployment. Official unemployment statistics measure only part of the problem.

The aging of populations and labor forces influences who can and will bear the burden of adjusting to changing labor requirements. Other things being equal, the greater the proportion of older workers, the faster will attri-

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[83] Bruce Vernyi, "GE Investing $100M in Refrigerator Line," *American Metal Market/Metalworking News*, July 25, 1983.

[84] See "GE to Improve Some Businesses for $590 Million," *The Wall Street Journal*, Nov. 2, 1983. A $362 million investment by GE in plant and equipment for aircraft engines and controls will affect 1,215 employees in two cities. GE plans to reassign many workers, provide "special education and retraining assistance," and sponsor placement programs for personnel choosing to leave.

[85] "U.S. Population Seen Hitting Peak in 2050 of 308.9 Million," *The Wall Street Journal*, Nov. 9, 1982; and H. N. Fullerton, Jr., and J. Tschetter, "The 1995 Labor Force: A Second Look," *Monthly Labor Review*, November 1983.

Table 41.—U.S. Population by Age Groups, 1929-83 (thousands of persons)

July 1	Total	Age (years)						
		Under 5	5-15	16-19	20-24	25-44	45-64	65 and over
1929	121,767	11,734	26,800	9,127	10,694	35,862	21,076	6,474
1933	125,579	10,612	26,897	9,302	11,152	37,319	22,933	7,363
1939	130,880	10,418	25,179	9,822	11,519	39,354	25,823	8,764
1940	132,122	10,579	24,811	9,895	11,690	39,868	26,249	9,031
1941	133,402	10,850	24,516	9,840	11,807	40,383	26,718	9,288
1942	134,860	11,301	24,231	9,730	11,955	40,861	27,196	9,584
1943	136,739	12,016	24,093	9,607	12,064	41,420	27,671	9,867
1944	138,397	12,524	23,949	9,561	12,062	42,016	28,138	10,147
1945	139,928	12,979	23,907	9,361	12,036	42,521	28,630	10,494
1946	141,389	13,244	24,103	9,119	12,004	43,027	29,064	10,828
1947	144,126	14,406	24,468	9,097	11,814	43,657	29,498	11,185
1948	146,631	14,919	25,209	8,952	11,794	44,288	29,931	11,538
1949	149,188	15,607	25,852	8,788	11,700	44,916	30,405	11,921
1950	152,271	16,410	26,721	8,542	11,680	45,672	30,849	12,397
1951	154,878	17,333	27,279	8,446	11,552	46,103	31,362	12,803
1952	157,553	17,312	28,894	8,414	11,350	46,495	31,884	13,203
1953	160,184	17,638	30,227	8,460	11,062	46,786	32,394	13,617
1954	163,026	18,057	31,480	8,637	10,832	47,001	32,942	14,076
1955	165,931	18,566	32,682	8,744	10,714	47,194	33,506	14,525
1956	168,903	19,003	33,994	8,916	10,616	47,379	34,057	14,938
1957	171,984	19,494	35,272	9,195	10,603	47,440	34,591	15,388
1958	174,882	19,887	36,445	9,543	10,756	47,337	35,109	15,806
1959	177,830	20,175	37,368	10,215	10,969	47,192	35,663	16,248
1960	180,671	20,341	38,494	10,683	11,134	47,140	36,203	16,675
1961	183,691	20,522	39,765	11,025	11,483	47,084	36,722	17,089
1962	186,538	20,469	41,205	11,180	11,959	47,013	37,255	17,457
1963	189,242	20,342	41,626	12,007	12,714	46,994	37,782	17,778
1964	191,889	20,165	42,297	12,736	13,269	46,958	38,338	18,127
1965	194,303	19,824	42,938	13,516	13,746	46,912	38,916	18,451
1966	196,560	19,208	43,702	14,311	14,050	47,001	39,534	18,755
1967	198,712	18,563	44,244	14,200	15,248	47,194	40,193	19,071
1968	200,706	17,913	44,622	14,452	15,786	47,721	40,846	19,365
1969	202,677	17,376	44,840	14,800	16,480	48,064	41,437	19,680
1970	205,052	17,166	44,816	15,289	17,202	48,473	41,999	20,107
1971	207,661	17,244	44,591	15,688	18,159	48,936	42,482	20,561
1972	209,896	17,101	44,203	16,039	18,153	50,482	42,898	21,020
1973	211,909	16,851	43,582	16,446	18,521	51,749	43,235	21,525
1974	213,854	16,487	42,989	16,769	18,975	53,051	43,522	22,061
1975	215,973	16,121	42,508	17,017	19,527	54,302	43,801	22,696
1976	218,035	15,617	42,099	17,194	19,986	55,852	44,008	23,278
1977	220,239	15,564	41,298	17,276	20,499	57,561	44,150	23,892
1978	222,585	15,735	40,428	17,288	20,946	59,400	44,286	24,502
1979	225,055	16,063	39,552	17,242	21,297	61,379	44,390	25,134
1980	227,704	16,457	38,820	17,136	21,612	63,474	44,493	25,714
1981	229,849	16,943	38,046	16,682	21,946	65,496	44,476	26,260
1982	232,057	17,372	37,620	16,205	21,935	67,625	44,474	26,824
1983	234,249							

Note.—Includes Armed Forces overseas beginning 1940. Includes Alaska and Hawaii beginning 1950.

SOURCE: Department of Commerce, Bureau of Census.

tion through retirement (normal or early) reduce the population at risk of displacement. However, involuntary retirement is tantamount to layoff, and it may be a source of effective unemployment.

For those eligible for pensions or social security, labor force withdrawal is a more viable alternative to a prolonged job search than it is for younger persons, who are less likely to have alternative sources of income.[88]

BLS has forecast that the proportion of employees aged 55 and older will fall in the 1980's and 1990's, in part because of anticipated declines in labor force participation.[89] At the same time, there will be growth in the share of 25- to 54-year-old employees, the prime age group. Change in the age mix (and other demographic phenomena, such as labor force participation rates), will also lead to changes in

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[88] Philip L. Rones, "Labor Market Problems of Older Workers," *Monthly Labor Review*, May 1983.

[89] H. N. Fullerton, Jr., and J. Tschetter, "The 1995 Labor Force: A Second Look," *Monthly Labor Review*, November 1983.

Table 42.—U.S. Population and Labor Force, 1929-83 (monthly data seasonally adjusted, except as noted)

Period	Civilian noninstitutional population[1]	Resident Armed Forces[1]	Labor force including resident Armed Forces	Employment including resident Armed Forces	Civilian labor force					Unemployment rate		Labor force participation rate	
					Total	Employment			Unemployment	All workers[2]	Civilian workers	Total[3]	Civilian[4]
						Total	Agricultural	Nonagricultural					
	Thousands of persons 14 years of age and over									Percent			
1929					49,180	47,630	10,450	37,180	1,550		3.2		
1933					51,590	38,760	10,090	28,670	12,830		24.9		
1939					55,230	45,750	9,610	36,140	9,480		17.2		
1940	99,840				55,640	47,520	9,540	37,980	8,120		14.6		55.7
1941	99,900				55,910	50,350	9,100	41,250	5,560		9.9		56.0
1942	98,640				56,410	53,750	9,250	44,500	2,660		4.7		57.2
1943	94,640				55,540	54,470	9,080	45,390	1,070		1.9		58.7
1944	93,220				54,630	53,960	8,950	45,010	670		1.2		58.6
1945	94,090				53,860	52,820	8,580	44,240	1,040		1.9		57.2
1946	103,070				57,520	55,250	8,320	46,930	2,270		3.9		55.8
1947	106,018				60,168	57,812	8,256	49,557	2,356		3.9		56.8
	Thousands of persons 16 years of age and over												
1947	101,827				59,350	57,038	7,890	49,148	2,311		3.9		58.3
1948	103,068				60,621	58,343	7,629	50,714	2,276		3.8		58.8
1949	103,994				61,286	57,651	7,658	49,993	3,637		5.9		58.9
1950	104,995	1,169	63,377	60,087	62,208	58,918	7,160	51,758	3,288	5.2	5.3	59.7	59.2
1951	104,621	2,143	64,160	62,104	62,017	59,961	6,726	53,235	2,055	3.2	3.3	60.1	59.3
1952	105,231	2,386	64,524	62,636	62,138	60,250	6,500	53,749	1,883	2.9	3.0	60.0	59.0
1953[5]	107,056	2,231	65,246	63,410	63,015	61,179	6,260	54,919	1,834	2.8	2.9	59.7	58.9
1954	108,321	2,142	65,785	62,251	63,643	60,109	6,205	53,904	3,532	5.4	5.5	59.6	58.8
1955	109,683	2,064	67,087	64,234	65,023	62,170	6,450	55,722	2,852	4.3	4.4	60.0	59.3
1956	110,954	1,965	68,517	65,764	66,552	63,799	6,283	57,514	2,750	4.0	4.1	60.7	60.0
1957	112,265	1,948	68,877	66,019	66,929	64,071	5,947	58,123	2,859	4.2	4.3	60.3	59.6
1958	113,727	1,847	69,486	64,883	67,639	63,036	5,586	57,450	4,602	6.6	6.8	60.1	59.5
1959	115,329	1,788	70,157	66,418	68,369	64,630	5,565	59,065	3,740	5.3	5.5	59.9	59.3
1960[5]	117,245	1,861	71,489	67,639	69,628	65,778	5,458	60,318	3,852	5.4	5.5	60.0	59.4
1961	118,771	1,900	72,359	67,646	70,459	65,746	5,200	60,546	4,714	6.5	6.7	60.0	59.3
1962[5]	120,153	2,061	72,675	68,763	70,614	66,702	4,944	61,759	3,911	5.4	5.5	59.5	58.8
1963	122,416	2,006	73,839	69,768	71,833	67,762	4,687	63,076	4,070	5.5	5.7	59.3	58.7
1964	124,485	2,018	75,109	71,323	73,091	69,305	4,523	64,782	3,786	5.0	5.2	59.4	58.7
1965	126,513	1,946	76,401	73,034	74,455	71,088	4,361	66,726	3,366	4.4	4.5	59.5	58.9
1966	128,058	2,122	77,892	75,017	75,770	72,895	3,979	68,915	2,875	3.7	3.8	59.8	59.2
1967	129,874	2,218	79,565	76,590	77,347	74,372	3,844	70,527	2,975	3.7	3.8	60.2	59.6
1968	132,028	2,253	80,990	78,173	78,737	75,920	3,817	72,103	2,817	3.5	3.6	60.3	59.6
1969	134,335	2,238	82,972	80,140	80,734	77,902	3,606	74,296	2,832	3.4	3.5	60.8	60.1
1970	137,085	2,118	84,889	80,796	82,771	78,678	3,463	75,215	4,093	4.8	4.9	61.0	60.4
1971	140,216	1,973	86,355	81,340	84,382	79,367	3,394	75,972	5,016	5.8	5.9	60.7	60.2
1972[5]	144,126	1,813	88,847	83,966	87,034	82,153	3,484	78,669	4,882	5.5	5.6	60.9	60.4
1973[5]	147,096	1,774	91,203	86,838	89,429	85,064	3,470	81,594	4,365	4.8	4.9	61.3	60.8
1974	150,120	1,721	93,670	88,515	91,949	86,794	3,515	83,279	5,156	5.5	5.6	61.7	61.3
1975	153,153	1,678	95,453	87,524	93,775	85,846	3,408	82,438	7,929	8.3	8.5	61.6	61.2
1976	156,150	1,668	97,826	90,420	96,158	88,752	3,331	85,421	7,406	7.6	7.7	62.0	61.6
1977	159,033	1,656	100,665	93,673	99,009	92,017	3,283	88,734	6,991	6.9	7.1	62.6	62.3
1978[5]	161,910	1,631	103,882	97,679	102,251	96,048	3,387	92,661	6,202	6.0	6.1	63.5	63.2
1979	164,863	1,597	106,559	100,421	104,962	98,824	3,347	95,477	6,137	5.8	5.8	64.0	63.7
1980	167,745	1,604	108,544	100,907	106,940	99,303	3,364	95,938	7,637	7.0	7.1	64.1	63.8
1981	170,130	1,645	110,315	102,042	108,670	100,397	3,368	97,030	8,273	7.5	7.6	64.2	63.9
1982	172,271	1,668	111,872	101,194	110,204	99,526	3,401	96,125	10,678	9.5	9.7	64.3	64.0
1983	174,215	1,676	113,226	102,510	111,550	100,834	3,383	97,450	10,717	9.5	9.6	64.4	64.0

[1] Not seasonally adjusted.

[2] Unemployed as percent of labor force including resident Armed Forces.

[3] Labor force including resident Armed Forces as percent of noninstitutional population including resident Armed Forces.

[4] Civilian labor force as percent of civilian noninstitutional population.

[5] Not strictly comparable with earlier data due to population adjustments as follows: Beginning 1953, introduction of 1950 census data added about 600,000 to population and about 350,000 to labor force, total employment, and agricultural employment. Beginning 1960, inclusion of Alaska and Hawaii added about 500,000 to population, about 300,000 to labor force, and about 240,000 to nonagricultural employment. Beginning 1962, introduction of 1960 census data reduced population by about 50,000 and labor force and employment by about 200,000. Beginning 1972, introduction of 1970 census data added about 800,000 to civilian noninstitutional population and about 333,000 to labor force and employment. A subsequent adjustment based on 1970 census in March 1973 added 60,000 to labor force and to employment. Beginning 1978, changes in sampling and estimation procedures introduced into the household survey added about 250,000 to labor force and to employment. Unemployment levels and rates were not significantly affected.

SOURCE: Department of Labor, Bureau of Labor Statistics.

aggregate buying patterns, which will in turn affect production and employment. For example, spending by and for older citizens will grow in absolute terms and relative to spending on child-rearing expenses.

Given the tendency of employers in the United States (and other industrialized nations) to reward seniority by lowering the risk of layoff as tenure rises, the loss of job opportunities associated with programmable automation or business slowdowns first affects younger workers and new job seekers.[88] Many analysts believe that slow growth in the numbers of young adults will lessen competition for manufacturing jobs, lowering the risk of unemployment in manufacturing industries. This may particularly affect durable manufacturing, since workers tend to move out of jobs in those industries as they age. Also, while middle-aged workers are generally not recruited for entry-level jobs, they may begin to fill such jobs in the wake of the decline of younger worker groups. Declining numbers of young workers may also have a favorable effect on unemployment rates generally, since teenagers have accounted for about one-tenth of the population but about one-fourth of cyclical employment variation.[89]

An older labor force means a more experienced work force. Shortages of experienced workers have been cited by employers in the past as a justification for automating. For example, manufacturers have cited the aging and retirement of experienced metalworking craftsmen as a motivation for automating machining operations. On the other hand, new technology, especially rapidly changing technology, may make fresh training more important than experience for some categories of technical personnel. This is believed to be increasingly so for engineers, for example.[90] Skills obsolescence may inhibit the substitution of more available middle-aged and older workers for declining numbers of younger workers, or it may stimulate industrial retraining. An increase in the incidence of unemployment among older workers may raise new concerns. Once displaced, the oldest workers (55 and over) apparently have the longest spells of unemployment, are most likely to suffer pay cuts upon obtaining a new job after being unemployed, and are least likely to change occupations.[91] A major uncertainty is whether and how employers will adapt their personnel practices in response to new technological and demographic conditions.

The contrast between the United States and Japan in rates and extent of adoption of programmable automation reflects in part their differences in population and age structure. The Japanese population aged more quickly than that of the United States (reflecting the lack of a "baby boom" in the postwar years comparable to that in the United States) (see table 43). Since the late 1960's, the Japanese have experienced labor shortages that helped to motivate their adoption of PA. In part, those shortages arose from slow growth in new labor force entrants; in part, they grew out of national norms, including lower female labor force participation, preference for single-shift employment, early mandatory retirement (between 50 and 60), and growing unwillingness of high school graduates to do unpleasant physical work.[92]

Finally, the U.S. labor force will also develop a "new look" due to growing proportions of minority and female workers. Programmable automation may have an important effect on minority employment, in particular, since blacks and Hispanics are now relatively well represented in manufacturing jobs, especially in the lower skilled operative and laborer

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[88] See, for example, Robert E. Hall, "The Importance of Lifetime Jobs in the U.S. Economy," *American Economic Review*, vol. 72(4), September 1982.

[89] U.S. Department of Labor, Office of the Assistant Secretary for Policy, Evaluation, and Research, "The Demographic Composition of Cyclical Variations in Employment," Technical Analysis Paper No. 61, January, 1979.

[90] Douglas Braddock, "Engineers—Higher Than Average Risk of Obsolescence?" *Occupational Outlook Quarterly*, summer 1983.

[91] See Philip L. Rones, "The Labor Market Problems of Older Workers," and Malcolm H. Morrison, "The Aging of the U.S. Population: Human Resource Implications" both in *Monthly Labor Review*, May 1983.

[92] See Robert E. Cole, "Participation and Control in Japanese Industry," paper prepared for Conference on Productivity, Ownership, and Participation, Agency for International Development, U.S. Department of Labor, May 1983; and Kazuo Koike, "Japanese Workers in Large Firms."

Table 43.—Japanese Population and Forecast (both sexes) (thousand persons)

(Years of age)	1950	1960	1970	1980	1990	2000	2010	2020	2030	2040	2050
0 - 14 (years of age)	29.428	28,067	24,823	27,546	23,327	21,180	22,210	19,402	17,588	17,865	15,960
0 - 4	11,205	7,844	8,806	8,564	7,002	7,427	7,162	5,897	6,022	5,816	4,924
5 - 9	9,523	9,205	8,159	10,035	7,862	6,823	7,691	6,410	5,724	6,084	5,275
10 - 14	8,700	11,018	7,858	8,947	8,463	6,930	7,357	7,095	5,842	5,965	5,761
15 - 64 (years of age)	49,658	60,002	71,566	78,790	86,325	86,880	82,942	78,343	75,747	68,578	64,465
15 - 19	8,568	9,309	9,064	8,232	10,007	7,847	6,813	7,680	6,402	5,717	6,075
20 - 24	7,726	8,318	10,660	7,811	8,913	8,440	6,915	7,342	7,079	5,830	5,952
25 - 29	6,185	8,209	9,089	9,073	8,183	9,964	7,819	6,788	7,653	6,378	5,696
30 - 34	5,202	7,518	8,372	10,786	7,758	8,868	8,406	6,886	7,312	7,051	5,806
35 - 39	5,048	6,038	8,207	9,215	9,002	8,135	9,918	7,782	6,757	7,617	6,349
40 - 44	4,483	5,019	7,340	8,322	10,679	7,697	8,808	8,349	6,839	7,262	7,002
45 - 49	4,005	4,817	5,878	8,092	9,082	8,897	8,048	9,811	7,699	6,684	7,535
50 - 54	3,389	4,201	4,805	7,158	8,132	10,481	7,572	8,663	8,211	6,727	7,142
55 - 59	2,749	3,641	4,425	5,632	7,803	8,819	8,651	7,824	9,539	7,458	6,498
60 - 64	2,304	2,932	3,726	4,469	6,766	7,732	9,992	7,218	8,256	7,827	6,410
65 and over	4,109	5,350	7,331	10,580	14,609	21,174	26,964	31,029	29,479	29,590	28,872
65 - 69	1,771	2,160	2,984	3,939	5,152	7,177	8,151	7,994	7,226	8,811	6,913
70 - 74	1.282	1,564	2,134	2,995	3,838	5,894	6,780	8,758	6,327	7,231	6,856
75 - 79	686	955	1,268	2,024	2,997	4,088	5,769	6,554	6,425	5,801	7,074
80 - 84	276	483	650	1,088	1,823	2,566	4,083	4,694	6,057	4,376	4,994
85 and over	95	188	296	533	799	1,499	2,181	3,029	3,444	3,371	3,035
Grand total	83,200	93,419	103,720	116,916	124,261	129,234	132,116	128,774	122,814	116,033	109,297

SOURCE: Japan Economic Research Center.

categories (see table 44). Minorities may not be well-positioned in the event that manufacturers seek to upgrade educational qualifications, since they are much more likely than whites to have fewer than 12 years of education (see table 45). Also, minorities are disproportionately likely to experience labor market discouragement.[93] Finally, while working women are principally employed in trade and service industries, about 15 percent work in manufacturing. Almost half of female manufacturing personnel are operatives, an occupational category especially susceptible to displacement.[94]

Japanese Mechanisms of Adjustment

Given the great attention now paid to Japanese manufacturing practices and labor management relations, it is useful to examine how Japanese firms have adjusted their work forces with the adoption of automation during periods generally characterized by output growth. Japanese experience reveals that the unique industrial and social stratification practiced there shapes—and to some extent obscures—the incidence of displacement.

Japanese manufacturers who automate often protect their work forces by altering their use of subcontractors and suppliers, transferring personnel, and changing work hours, as well as by increasing output. These are fairly conventional approaches worldwide. However, other Japanese practices are more peculiar to the Japanese context, and are now a source of controversy in Japan, as they would certainly be in the United States. These include the "preferential" laying off of workers such as women, part-time, temporary, and middle-aged and older people.

A recent Japanese survey reported decreased reliance on outside firms and the internalization of more aspects of production, with an accompanying 20 percent or more decrease in women and part-time (mostly female) workers. At the same time, the use of microelectronics technologies had wrought considerable changes for 70 percent of users. Working hours fell (or a second shift was adopted), and on average, production employment fell by 40 percent, with affected personnel being absorbed by transfer to other work.[95] The survey of Japanese electrical machinery workers reported a 60 percent overall decline in staffing caused by microelectronics, affecting peripheral as well as immediate tasks; more often than not, temporary and part-time employment fell first with the introduction of microelectronics.[96] Interestingly, that survey reported that workers perceived a problem of understaffing.

More detailed evidence comes from recent Japanese case studies. In one transistor and integrated circuit plant, before automation, there was one person per machine; after automation the ratio was one to two, production scheduling went from multiple to two shifts, and people were laid off. In a relay-manufacturing plant, the introduction of robots led to a reduction in overtime and the allocation of workers to other tasks elsewhere in the plant. The adoption of an automatic component processing system in an electronic cash register plant resulted in a work force decrease from 100 to 65 (chiefly by laying off women) and the movement of work (20 percent) in-house that was previously performed by subcontractors. Finally, an automobile manufacturer found that robots allowed the direct labor time required in small-car manufacture to decline by about one-half during the 1970's, but output growth allowed employment to rise. However, seasonal and temporary employment fell.[97]

These practices reflect the fact that the vaunted Japanese system of "permanent employment" is largely limited to male workers

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[93] Philip L. Rones, "The Labor Market Problems of Older Workers," *Monthly Labor Review*, May 1983.

[94] U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings*, May 1983.

[95] "Ministry of Labor Report on Microelectronics and Its Impact on Labor," cable from American Embassy (Tokyo) to U.S. Secretary of State, August 1983.

[96] Denki Roren, "Surveys on the Impacts of Micro-Electronics and Our Policies Towards Technological Innovation," paper presented at the 4th IMF World Conference for the Electrical and Electronics Industries, Oct. 3-5, 1983.

[97] Japan Labor Association, "A Special Study Concerning Technological Innovation and Labor-Management Relations," Interim Report, June 1983.

Table 44.—Minority Employment Patterns

Employed black and Hispanic-origin workers by occupation (numbers in thousands)

Occupation	1982		
	Total employed	Percent of total	
		Black	Hispanic origin
Total, 16 years and over	99,526	9.2	5.2
White-collar workers	53,470	6.6	3.5
Professional and technical	16,951	6.4	2.6
Health workers	3,263	7.3	2.5
Teachers, except college	3,266	9.0	2.4
Other professional and technical	10,422	5.3	2.7
Managers and administrators, except farm	11,493	3.9	2.9
Salaried workers	9,630	4.0	2.8
Self employed workers in retail trade	838	3.3	4.8
Self-employed workers, except retail trade	1,026	3.5	3.1
Sales workers	6,580	3.8	3.3
Retail trade	3,310	4.9	4.3
Other industries	3,270	2.8	2.3
Clerical workers	18,446	9.4	4.8
Stenographers, typists, and secretaries	4,855	7.5	4.1
Other clerical workers	13,591	10.1	5.1
Blue-collar workers	29,597	10.9	7.5
Craft and kindred workers	12,272	6.7	5.5
Carpenters	1,082	4.2	4.9
Construction craft workers, except carpenters	2,509	8.4	5.4
Mechanics and repairers	3,358	6.2	5.6
Metal craft workers	1,168	7.1	5.6
Blue-collar worker supervisors, not elsewhere classified	1,688	6.7	5.2
Craft and kindred workers—Continued			
All other craft workers	2,467	6.6	6.0
Operatives, except transport	9,429	13.5	10.0
Durable goods manufacturing	3,966	12.5	9.8
Nondurable goods manufacturing	3,054	16.3	11.2
Other industries	2,409	11.5	8.8
Transport equipment operatives	3,377	13.1	6.5
Drivers, motor vehicles	2,921	12.5	6.1
All other	456	17.5	9.2
Nonfarm laborers	4,519	15.1	8.2
Construction	722	16.6	10.7
Manufacturing	880	15.7	8.6
Other industries	2,916	14.6	7.5
Service workers	13,736	16.7	6.3
Private household workers	1,042	28.2	8.2
Service workers, except private household	12,694	15.7	6.2
Food service workers	4,760	10.2	6.4
Protective service workers	1,546	13.8	4.0
All other	6,388	20.4	6.5
Farm workers	2,723	5.5	7.[illegible]
Farmers and farm managers	1,452	1.2	[illegible]
Farm laborers and supervisors	1,271	10.4	14.5
Paid workers	1,028	12.7	17.8
Unpaid family workers	244	.4	.4

Employed black and Hispanic-origin workers by industry (numbers in thousands)

Industry	1982		
	Total employed	Percent of total	
		Black	Hispanic origin
Total, 16 years and over	99,526	9.2	5.2
Agriculture	3,401	5.5	7.4
Mining	1,028	3.0	5.4
Construction	5,756	6.6	5.3
Manufacturing	20,286	9.4	6.5
Durable goods	11,968	8.4	6.1
Lumber and wood products	627	13.7	5.4
Furniture and fixtures	461	6.9	11.9
Stone, clay, and glass products	539	9.5	6.9
Primary metal industries	925	12.1	7.7
Fabricated metal products	1,264	7.2	8.0
Machinery, except electrical equipment	2,558	5.8	4.7
Electrical equipment	2,295	7.4	6.0
Transportation equipment	1,931	11.4	3.4
Automobiles	853	13.7	2.7
Other transportation equipment	1,078	9.6	4.1
Instruments and related products	600	7.2	6.0
Other durable goods industries	768	6.0	9.4
Nondurable goods	8,318	10.8	7.0
Food and kindred products	1,733	10.6	9.6
Textile mill products	688	18.3	4.1
Apparel and other textile products	1,150	13.6	14.9
Paper and allied products	689	10.2	3.9
Printing and publishing	1,621	5.8	3.5
Chemicals and allied products	1,213	11.3	3.6
Rubber and plastics products	643	9.0	7.0
Nondurable goods—Continued			
Other nondurable goods industries	581	12.6	7.1
Transportation and public utilities	6,552	11.0	4.8
Railroads and railway express	469	10.0	3.0
Other transportation	3,121	11.0	5.7
Communications and other public utilities	2,961	11.2	4.1
Wholesale and retail trade	20,758	6.5	5.0
Wholesale trade	4,120	5.4	4.8
Retail trade	16,638	6.8	5.0
Finance, insurance, and real estate	6,270	7.7	4.6
Service industries	30,259	11.4	4.6
Private household	1,271	26.4	7.8
Other service industries	28,988	10.7	4.4
Business repair services	4,452	8.4	5.6
Personal services	2,722	11.3	6.9
Entertainment and recreation services	1,138	6.9	4.6
Professional services	20,507	11.4	3.8
Medical, except hospital	3,518	11.1	3.9
Hospitals	4,341	15.8	3.9
Welfare and religion	1,594	14.6	5.0
Education	8,089	11.1	3.9
Other	2,965	4.5	2.8
Forestry and fisheries	168	4.2	3.6
Public administration	5,218	13.4	4.3

SOURCES: U.S. Department of Labor, *Employment and Earnings* (household data, annual averages), May 1983.

Table 45.—Relative Educational Attainment (years of school completed of the civilian labor force by age, sex, and total race: 1980)

United States	Total		White		Black		American Indian, Eskimo, and Aleut		Asian and Pacific Islander		Race, n.e.c.	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Total, 16 years and over	59,926,488	44,523,329	51,884,626	37,307,269	5,330,792	5,251,644	333,571	250,908	947,280	825,596	1,430,219	887,912
Less than 12 years of school	16,222,652	10,159,951	12,911,874	7,771,259	2,190,803	1,698,293	127,689	81,413	168,430	170,231	823,856	438,755
12 years of school	21,080,014	18,733,366	18,596,168	16,143,347	1,805,410	1,981,651	116,474	99,176	215,261	234,536	346,701	274,656
13 to 15 years of school	10,858,576	8,853,090	9,553,401	7,476,901	871,704	1,018,719	61,129	51,557	193,337	178,275	179,005	127,638
16 years of school	5,961,883	3,928,845	5,514,833	3,450,474	246,877	315,042	13,863	10,349	148,145	127,914	38,165	25,066
17 or more years of school	5,803,363	2,848,077	5,308,350	2,465,288	215,998	237,939	14,416	8,413	222,107	114,640	42,492	21,797
Total, 16 to 19 years	4,327,040	3,821,588	3,723,280	3,299,319	393,790	356,351	29,623	24,531	49,033	45,693	131,314	95,694
Less than 12 years of school	2,744,650	2,049,147	2,326,551	1,755,939	269,180	192,809	20,725	15,077	28,259	23,190	99,935	62,132
12 years of school	1,355,987	1,456,739	1,197,645	1,271,856	108,070	132,581	8,034	8,274	15,202	15,736	27,036	28,292
13 to 15 years of school	225,867	315,190	198,645	271,073	16,494	30,924	855	1,180	5,554	6,743	4,319	5,270
16 years of school	408	466	321	405	45	37	3	—	18	24	20	—
17 or more years of school	128	46	118	46	—	—	5	—	—	—	4	—
Total, 20 to 24 years	8,263,921	7,159,960	6,972,907	5,957,291	835,619	860,510	57,692	44,761	107,197	107,088	290,506	190,310
Less than 12 years of school	1,592,999	802,539	1,180,568	570,260	237,959	147,281	19,134	9,868	13,879	11,483	141,459	63,647
12 years of school	3,792,265	3,219,990	3,259,965	2,708,832	377,032	383,484	26,276	21,503	33,892	31,747	95,100	74,424
13 years to 15 years of school	2,142,726	2,292,112	1,856,557	1,925,094	185,589	266,266	10,742	11,685	43,492	44,454	46,346	44,613
16 years of school	584,405	712,315	538,831	637,534	28,506	53,656	1,059	1,358	10,743	14,047	5,266	5,720
17 or more years of school	151,526	133,004	136,986	115,571	6,533	9,823	481	347	5,191	5,357	2,335	1,906
Total, 25 to 29 years	8,619,669	6,464,535	7,291,610	5,256,841	847,620	864,187	54,739	41,656	145,761	139,224	279,939	162,627
Less than 12 years of school	1,250,521	698,572	893,364	467,608	199,207	147,419	14,092	8,167	15,273	16,889	128,585	58,489
12 years of school	3,195,756	2,531,940	2,711,880	2,056,606	350,632	369,717	22,355	17,858	30,769	31,170	80,120	56,589
13 to 15 years of school	2,094,412	1,591,880	1,793.909	1,298,401	198,268	215,174	13,231	11,242	39,053	35,217	49,951	31,846
16 years of school	1,224,142	1,033,079	1,118,074	903,150	65,500	88,389	2,811	2,734	26,893	29,868	10,864	8,938
17 or more years of school	854,838	609,064	774,383	531,076	34,013	43,488	2,250	1,655	33,773	26,080	10,419	6,765
Total, 30 to 34 years	8,035,553	5,647,299	6,880,960	4,589,364	728,309	751,094	49,304	37,410	162,205	143,625	214,775	125,806
Less than 12 years of school	1,160,683	756,784	843,409	516,412	184,164	155,476	12,053	8,691	14,731	20,557	106,326	55,648
12 years of school	2,579,525	2,331,754	2,206,051	1,925,320	276,010	317,065	17,969	15,367	27,214	32,065	52,281	41,937
13 to 15 years of school	1,870,915	1,252,612	1,620,551	1,021,973	167,960	172,246	13,020	9,207	33,782	30,169	35,602	19,017
16 years of school	1,189,947	676,855	1,090,094	583,029	54,151	56,713	3,116	2,256	33,083	30,647	9,503	4,210
17 or more years of school	1,234,483	629,294	1,120,855	542,630	46,024	49,594	3,146	1,889	53,395	30,187	11,063	4,994
Total, 35 to 39 years	6,334,497	4,574,280	5,466,520	3,778,441	556,144	570,894	38,114	29,153	128,939	105,897	144,780	89,895
Less than 12 years of school	1,229,649	813,962	932,100	579,941	188,021	159,539	12,456	8,590	12,798	17,404	84,274	48,488
12 years of school	2,237,539	2,038,954	1,964,043	1,741,774	206,858	232,939	13,320	11,838	21,303	26,091	32,015	26,312
13 to 15 years of school	1,159,738	874,367	1,019,616	731,276	94,509	108,282	7,808	6,073	20,985	18,511	16,820	10,225
16 years of school	726,653	425,028	663,482	365,752	31,379	34,142	2,036	1,276	25,107	21,624	4,849	2,234
17 or more years of school	980,918	421,969	887,279	359,698	35,377	35,992	2,494	1,376	48,746	22,267	7,022	2,636
Total, 40 to 69 years	23,501,469	16,344,048	20,785,939	13,977,101	1,907,687	1,795,396	101,671	71,993	343,572	279,329	362,600	220,223
Less than 12 years of school	7,795,680	4,776,175	6,349,701	3,665,359	1,063,416	855,221	47,536	30,103	76,996	77,862	258,031	147,630
12 years of school	7,758,238	7,023,508	7,104,507	6,317,026	480,805	539,023	28,134	24,102	85,239	96,703	59,553	46,654
13 to 15 years of school	3,271,231	2,461,227	2,974,826	2,167,274	205,631	222,661	15,329	11,993	49,646	42,728	25,799	16,571
16 years of school	2,173,016	1,052,391	2,043,231	933,699	65,767	80,598	4,752	2,717	51,523	31,456	7,743	3,921
17 or more years of school	2,503,304	1,030,747	2,313,674	893,743	92,068	97,893	5,920	3,078	80,168	30,580	11,474	5,453
Total, 70 years and over	844,339	511,619	763,410	448,912	61,623	53,212	2,428	1,404	10,573	4,740	6,305	3,351
Less than 12 years of school	448,470	262,772	386,181	215,740	48,856	40,548	1,693	917	6,494	2,846	5,246	2,721
12 years of school	160,704	130,481	152,077	121,933	6,003	6,842	386	234	1,642	1,024	596	448
13 to 15 years of school	93,687	65,702	89,297	61,810	3,253	3,166	144	177	825	453	168	96
16 years of school	63,312	28,711	60,800	26,905	1,528	1,507	86	8	778	248	120	43
17 or more years of school	78,166	23,953	75,055	22,524	1,983	1,149	119	68	834	169	175	43

n.e.c.—Not elsewhere classified.
SOURCE: Bureau of the Census.

Table 46.—Employed Persons and Employees by Occupation, Japan (ten thousand persons)

Year	Total	Professional and technical workers	Managers and officials	Clerical and related workers	Sales workers	Farmers, lumbermen, and fishermen	Mining workers	Workers in transport and communication occupations	Craftsmen and production process workers	Labourers	Protective service workers and service workers
Employed persons:											
Both sexes: Annual average:											
1975	5,223	364	206	820	738	654	9	237	1,580	148	457
1976	5,271	380	215	828	754	634	10	242	1,589	151	457
1977	5,342	389	212	850	778	625	10	238	1,603	159	465
1978	5.408	399	204	871	791	626	7	243	1,611	160	486
1979	5,479	426	217	898	784	605	5	244	1,628	164	497
1980	5,536	438	220	924	797	570	5	248	1,653	168	501
1981	5,581	452	228	945	811	552	5	238	1,659	207	473
1982	5,638	471	220	973	838	543	4	237	1,648	210	480
Change over the year:											
1976	48	16	9	8	16	– 20	1	5	9	3	0
1977	71	9	– 3	22	24	– 9	0	– 4	14	8	8
1978	66	10	– 8	21	13	1	– 3	5	8	1	21
1979	71	27	13	27	– 7	– 21	– 2	1	17	4	11
1980	57	12	3	26	13	– 35	0	4	25	4	4
1981	45	14	8	21	14	– 18	0	– 10	6	39[b]	– 28[b]
1982	57	19	– 8	28	27	– 9	– 1	– 1	– 11	3	7
Change over the year:											
1976	0.9	4.4	4.4	1.0	2.2	– 3.1	*	2.1	0.6	2.0	0.0
1977	1.3	2.4	– 1.4	2.7	3.2	– 1.4	0.0	– 1.7	0.9	5.3	1.8
1978	1.2	2.6	– 3.8	2.5	1.7	0.2	– 30.0	2.1	0.5	0.6	4.5
1979	1.3	6.8	6.4	3.1	– 0.9	– 3.4	*	0.4	1.1	2.5	2.3
1980	1.0	2.8	1.4	2.9	1.7	– 5.8	*	1.6	1.5	2.4	0.8
1981	0.8	3.2	3.6	2.3	1.8	– 3.2	*	– 4.0	0.4	23.2[b]	– 5.6[b]
1982	1.0	4.2	– 3.5	3.0	3.3	– 1.6	*	– 0.4	– 0.7	1.4	1.5
Percentage distribution											
Both sexes: Annual average:											
1975	100.0	7.0	3.9	15.7	14.1	12.5	0.2	4.5	30.3	2.8	8.7
1976	100.0	7.2	4.1	15.7	14.3	12.0	0.2	4.6	30.1	2.9	8.7
1977	100.0	7.3	4.0	15.9	14.6	11.7	0.2	4.5	30.0	3.0	8.7
1978	100.0	7.4	3.8	16.1	14.6	11.6	0.1	4.5	29.8	3.0	9.0
1979	100.0	7.8	4.0	16.4	14.3	11.0	0.1	4.5	29.7	3.0	9.1
1980	100.0	7.9	4.0	16.7	14.4	10.3	0.1	4.5	29.9	3.0	9.0
1981	100.0	8.1	4.1	16.9	14.5	9.9	0.1	4.3	29.7	3.7	8.5
1982	100.0	8.4	3.9	17.3	14.9	9.6	0.1	4.2	29.2	3.7	8.5
Male: Change over the year:											
1975	100.0	6.3	6.0	12.4	14.0	10.0	0.3	6.7	34.9	2.9	6.3
1976	100.0	6.6	6.2	12.2	14.3	9.7	0.3	6.8	34.5	2.8	6.3
1977	100.0	6.6	6.1	12.2	14.6	9.6	0.3	6.7	34.4	3.0	6.2
1978	100.0	6.6	5.8	12.5	14.6	9.6	0.2	6.9	34.3	2.9	6.5
1979	100.0	6.7	6.1	12.6	14.3	9.1	0.1	6.8	34.3	2.9	6.7
1980	100.0	6.9	6.2	12.6	14.4	8.5	0.1	6.9	34.4	2.9	6.7
1981	100.0	7.1	6.3	12.7	14.6	8.4	0.1	6.6	34.2	3.5	6.3
1982	100.0	7.4	6.1	12.9	15.0	8.1	0.1	6.5	33.9	3.4	6.3
Female: Change over the year:											
1975	100.0	8.0	0.6	21.2	14.4	16.8	0.0	0.9	22.4	2.7	12.8
1976	100.0	8.2	0.6	21.6	14.3	15.9	0.0	0.9	22.9	2.9	12.6
1977	100.0	8.4	0.5	22.0	14.5	15.1	0.0	0.8	22.8	2.9	12.7
1978	100.0	8.7	0.5	21.9	14.7	14.8	0.0	0.7	22.7	3.0	12.9
1979	100.0	9.4	0.6	22.3	14.3	14.2	0.0	0.8	22.3	3.1	12.8
1980	100.0	9.6	0.5	23.1	14.3	13.1	0.0	0.7	22.6	3.1	12.7
1981	100.0	9.7	0.6	23.6	14.4	12.3	0.0	0.6	22.7	4.1	11.8
1982	100.0	9.8	0.5	24.0	14.6	12.0	0.0	0.6	22.0	4.3	12.0

[a] The Occupational Classifications for the Labour Force Survey were revised in January 1981 to correspond to the Occupational Classifications used in the 1980 Population Census. "Workers in mining and quarrying occupations" have been reclassified as "Mining workers," and "Sweepers and garbage men," previously listed as "Protective service and service workers" are classified as "Labourers" in the current survey.

[b] As of January 1981, there were 320,000 "Sweepers and garbage men," 100,000 male and 230,000 female.

Take the above explanation into consideration when the difference or percentage for year-to-year change of monthly estimates are used.

SOURCE: "Annual Report of the Labour Force Survey," Statistics Bureau, Office of the Prime Minister, Japan, 1982.

Table 46.—Employed Persons and Employees by Occupation, Japan (ten thousand persons)—Continued

Employees: Year	Total	Professional and technical workers	Managers and officials	Clerical and related workers	Sales workers	Farmers, lumbermen, and fishermen	Mining workers	Workers in transport and communication occupations	Craftsmen and production process workers	Labourers	Protective service workers and service workers
Both sexes: Annual average:											
1975	3,646	304	205	775	427	41	9	220	1,216	132	315
1976	3,712	316	214	783	448	41	9	225	1,224	135	315
1977	3,769	322	211	803	463	43	10	222	1,235	140	317
1978	3,799	329	201	818	470	40	7	226	1,233	141	331
1979	3,876	352	215	844	476	38	5	226	1,237	144	336
1980	3,971	364	217	867	497	40	4	229	1,260	148	342
1981	4,037	377	226	886	506	43	4	220	1,272	184	317
1982	4,098	394	217	909	537	41	4	220	1,269	187	315
Change over the year:											
1976	66	12	9	8	21	0	0	5	8	3	0
1977	57	6	−3	20	15	2	1	−3	11	5	2
1978	30	7	−10	15	7	−3	−3	4	−2	1	14
1979	77	23	14	26	6	−2	−2	0	4	3	5
1980	95	12	2	23	21	2	−1	3	23	4	6
1981	66	13	9	19	9	3	0	−9	12	36[b]	25[b]
1982	61	17	−9	23	31	−2	0	0	−3	3	−2
Change over the year (%):											
1976	1.8	3.9	4.4	1.0	4.9	0.0	*	2.3	0.7	2.3	0.0
1977	1.5	1.9	−1.4	2.6	3.3	4.9	*	−1.3	0.9	3.7	0.6
1978	0.8	2.2	−4.7	1.9	1.5	−7.0	−30.0	1.8	−0.2	0.7	4.4
1979	2.0	7.0	7.0	3.2	1.3	−5.0	*	0.0	0.3	2.1	1.5
1980	2.5	3.4	0.9	2.7	4.4	5.3	*	1.3	1.9	2.8	1.8
1981	1.7	3.6	4.1	2.2	1.8	7.5	*	−3.9	1.0	24.3[b]	7.3[b]
1982	1.5	4.5	−4.0	2.6	6.1	−4.7	*	0.0	−0.2	1.6	−0.6
Percentage distribution											
Both sexes: Change over the year (%):											
1975	100.0	8.3	5.6	21.3	11.7	1.1	0.2	6.0	33.4	3.6	8.6
1976	100.0	8.5	5.8	21.1	12.1	1.1	0.2	6.1	33.0	3.6	8.5
1977	100.0	8.5	5.6	21.3	12.3	1.1	0.3	5.9	32.8	3.7	8.4
1978	100.0	8.7	5.3	21.5	12.4	1.1	0.2	5.9	32.5	3.7	8.7
1979	100.0	9.1	5.5	21.8	12.3	1.0	0.1	5.8	31.9	3.7	8.7
1980	100.0	9.2	5.5	21.8	12.5	1.0	0.1	5.8	31.7	3.7	8.6
1981	100.0	9.3	5.6	21.9	12.5	1.1	0.1	5.4	31.5	4.6	7.9
1982	100.0	9.6	5.3	22.2	13.1	1.0	0.1	5.4	31.0	4.6	7.7
Male:											
1975	100.0	6.8	7.8	16.1	12.1	1.3	0.4	8.2	37.5	3.5	6.3
1976	100.0	7.1	8.1	15.8	12.5	1.3	0.4	8.3	36.9	3.5	6.2
1977	100.0	7.0	7.9	15.8	12.9	1.3	0.4	8.2	36.7	3.7	6.0
1978	100.0	6.9	7.6	16.3	12.8	1.2	0.3	8.4	36.5	3.6	6.4
1979	100.0	7.1	8.0	16.3	12.8	1.1	0.2	8.2	36.4	3.5	6.4
1980	100.0	7.2	7.9	16.2	13.0	1.1	0.2	8.2	36.1	3.6	6.4
1981	100.0	7.4	8.1	16.2	13.0	1.3	0.2	7.8	35.8	4.2	6.0
1982	100.0	7.7	7.6	16.4	13.7	1.2	0.1	7.7	35.6	4.0	5.8
Female:											
1975	100.0	11.6	0.9	32.2	11.1	0.8	0.0	1.5	24.6	3.7	13.7
1976	100.0	11.5	1.0	32.2	11.1	0.7	0.0	1.4	24.9	4.0	13.3
1977	100.0	11.7	0.9	32.4	11.1	0.7	0.0	1.2	24.8	3.8	13.3
1978	100.0	12.2	0.7	32.0	11.6	0.7	0.0	1.1	24.5	3.9	13.4
1979	100.0	13.1	0.8	32.4	11.4	0.7	0.0	1.2	23.3	4.0	13.1
1980	100.0	13.0	0.8	32.7	11.6	0.7	0.0	1.0	23.2	4.0	12.9
1981	100.0	13.1	0.9	32.9	11.6	0.6	0.0	0.9	23.3	5.3	11.4
1982	100.0	13.2	0.8	33.2	11.9	0.7	0.0	0.9	22.4	5.6	11.2

[a] The Occupational Classifications for the Labour Force Survey were revised in January 1981 to correspond to the Occupational Classifications used in the 1980 Population Census. "Workers in mining and quarrying occupations" have been reclassified as "Mining workers," and "Sweepers and garbage men" previously listed as "Protective service and service workers" are classified as "Labourers" in the current survey.

[b] As of January 1981, there were 320,000 "Sweepers and garbage men," 100,000 male and 230,000 female.

Take the above explanation into consideration when the difference or percentage for year-to-year change of monthly estimates are used.

NOTE: Employees are the subset of employed persons that is not self-employed.

SOURCE: "Annual Report of the Labour Force Survey," Statistics Bureau, Office of the Prime Minister, Japan, 1982.

in large firms.[98] Because of that system, nonetheless, Japanese employers are less free than U.S. employers to lay off personnel. They have an incentive to minimize hiring of "regular" employees, and to increase use of others whose ranks can more easily be cut (see tables 46 and 47).

Note that U.S. employers have increasingly resorted to the use of temporary personnel. The temporary-help service industry in the United States has been growing, and the proportion of temporaries comprised of such professionals as engineers, scientists, and technicians has also been growing. (Statistics are not available to show trends for manufacturing industries alone.) As noted by the National Association of Temporary Services:

> By hiring temporaries, companies can cut staff without layoffs. They can hire temporaries for short-term projects too large or too specialized for their permanent staff to handle.[99]

Because adopting PA raises companies' fixed costs, many of them might seek to increase reliance on temporaries or part-time personnel, where feasible, to lessen their vulnerability to downturns.

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[98] See Robert E. Cole, "Participation and Control in Japanese Industry," paper prepared for Conference on Productivity, Ownership, and Participation, Agency for International Development, U.S. Department of Labor, May 1983.

[99] Sam Sacco, "The World of High-Tech Temporaries," *Washington Post* (Advertising Supplement), Apr. 24, 1983.

Table 47.—Employed Persons by Industry and Status in Employment, Japan
(for employees, number of persons engaged in enterprise) (1982)

Industry	Total	Employees									Government employees
		1-29 persons			30 persons and over			500 persons and over			
		Total	1-4 persons	5-29 persons	Total	30-99 persons	100-499 persons	Total	500-999 persons	1,000 persons and over	
Both sexes											
1)	4,098	1,408	339	1,069	2,184	632	591	962	184	778	498
2)	30	18	7	11	6	3	2	1	—	—	6
3)	16	12	5	7	3	2	1	—	—	—	1
4)	14	6	2	5	3	2	1	—	—	—	5
5)	4,068	1,390	332	1,058	2,178	628	569	961	183	777	492
6)	14	8	1	7	6	3	2	1	—	1	—
7)	10	3	—	3	6	2	1	3	—	3	—
8)	423	257	56	201	164	78	38	48	10	38	—
9)	1,151	324	46	278	825	220	226	378	77	301	1
10)	125	48	7	40	77	33	28	17	5	12	—
11)	147	29	4	26	117	25	29	64	13	51	—
12)	557	120	16	103	437	91	106	239	42	197	—
13)	66	8	1	7	58	7	11	40	4	36	—
14)	103	49	8	40	54	24	17	13	5	8	—
15)	131	31	4	27	100	25	29	46	12	35	—
16)	158	21	2	19	137	25	34	78	12	66	—
17)	99	11	1	10	88	10	16	61	8	53	—
18)	322	127	19	108	194	71	64	59	17	42	1
19)	1,059	470	146	324	583	150	149	284	55	229	5
20)	870	443	135	309	423	139	126	159	42	117	3
21)	337	138	25	114	198	73	62	63	19	45	—
22)	534	305	110	195	225	66	63	96	23	72	3
23)	128	95	37	58	32	16	9	7	2	5	—
24)	189	27	12	15	160	11	23	125	12	113	2
25)	364	51	4	47	263	47	53	163	16	148	50
26)	331	51	4	46	240	46	51	142	15	127	39
27)	34	—	—	—	23	1	1	21	—	20	11
28)	847	276	77	199	329	127	119	83	25	57	241
29)	427	112	31	82	120	48	46	26	9	17	194
30)	420	163	45	118	209	79	73	57	17	40	47
31)	195	—	—	—	—	—	—	—	—	—	195
Percent male											
1)	65.40	60.30	55.75	61.74	68.09	63.13	65.82	72.66	71.20	73.01	67.87
9)	65.94	58.02	63.04	57.19	69.09	56.76	63.87	79.37	72.73	81.06	100.00
12)	73.25	68.33	75.00	66.99	74.60	63.74	67.92	81.59	73.81	83.25	—
14)	75.73	75.51	87.50	75.00	75.93	70.83	76.47	84.62	80.00	87.50	—
15)	77.10	74.19	75.00	74.07	78.00	76.00	72.41	82.61	75.00	82.86	—
16)	59.96	42.86	50.00	36.84	59.85	41.67	52.94	71.79	58.33	72.73	—
17)	80.81	63.64	100.00	70.00	82.95	70.00	75.00	88.52	87.50	88.68	—
Percent female											
1)	34.60	39.70	44.25	38.26	31.91	36.87	34.18	27.23	28.80	26.99	32.13
9)	34.06	41.98	39.13	42.45	31.03	42.34	36.73	20.63	27.27	19.27	100.00
12)	26.75	31.67	25.00	33.01	25.40	36.26	32.08	78.41	26.19	16.75	—
14)	23.30	24.49	25.00	25.00	22.22	25.00	25.53	15.38	20.00	12.50	—
15)	23.66	25.81	25.00	25.93	22.00	24.00	27.59	17.39	16.67	17.14	—
16)	43.04	57.14	50.00	57.89	40.88	62.50	47.06	29.49	41.67	27.27	—
17)	18.18	36.36	—	40.00	15.91	30.00	25.00	11.48	25.00	11.32	—

1) All industries
2) Agriculture and forestry
3) Agriculture
4) Forestry and hunting
5) Nonagricultural industires
6) Fisheries and aquaculture
7) Mining
8) Construction
9) Manufacturing
10) Textile mill products
11) Chemical and related products
12) Metal and machinery
13) Iron, steel and non-ferrous metal industries
14) Fabricated metal products
15) Machinery, weapons, and precision machine
16) Electrical machinery, equipment and supplies
17) Transportation equipment
18) Other manufacturing
19) Wholesale, retail trade, finance, insurance and real estate
20) Wholesale and retail trade
21) Wholesale trade
22) Retail trade
23) of which Eating and drinking place
24) Finance, insurance and real estate
25) Transport, communication, electricity, gas, water, steam and hot water supply
26) Transport and communication
27) Electricity, gas, water, steam and hot water supply
28) Services
29) Professional services
30) Other services
31) Government

SOURCE: "Annual Report of the Labour Force Survey," Statistics Bureau, Office of the Prime Minister, Japan, 1983.

Table 47.—Employed Persons by Industry and Status in Employment, Japan—Continued
(for employees, number of persons engaged in enterprise) (1982)

		Self-employed workers				Employees (regrouped)					
							Regular employees				
Industry	Total	Total	With employees	Without employees	Family workers	Total	Total	Ordinary regular employees	Directors	Temporary employees	Day labourers
Both sexes											
1)	5,638	943	193	750	587	4,098	3,692	3,399	294	278	127
2)	502	240	7	234	232	30	20	18	2	3	6
3)	484	237	6	232	231	16	10	9	1	2	3
4)	18	3	1	2	1	14	10	10	—	1	3
5)	5,136	702	186	516	355	4,068	3,672	3,380	292	275	121
6)	46	18	2	16	13	14	13	12	1	1	1
7)	10	—	—	—	—	10	9	9	1	—	—
8)	541	88	37	51	31	423	346	299	47	25	51
9)	1,380	161	29	132	68	1,151	1,053	978	75	75	24
10)	208	65	5	60	18	125	110	101	9	11	5
11)	166	13	2	10	6	147	138	131	7	7	2
12)	614	40	10	30	17	557	520	490	31	29	7
13)	67	1	—	—	1	66	64	62	3	1	—
14)	127	16	5	10	9	103	95	85	11	5	2
15)	143	8	2	5	4	131	125	115	10	6	1
16)	175	15	2	13	2	158	142	137	5	13	3
17)	102	1	1	1	1	99	94	91	3	4	1
18)	392	44	12	32	26	322	284	257	28	29	9
19)	1,501	258	77	181	183	1,059	948	830	118	90	22
20)	1,296	246	75	171	179	870	765	659	106	84	21
22)	376	24	8	16	16	337	323	278	45	10	4
22)	919	222	67	155	163	534	442	381	61	74	18
23)	237	67	33	34	41	128	95	85	10	26	7
24)	206	13	2	11	4	189	183	171	12	5	—
25)	382	15	2	12	3	364	350	339	11	11	3
26)	349	15	2	12	3	331	317	306	11	10	3
27)	34	—	—	—	—	34	33	32	—	1	—
28)	1,065	162	39	123	56	847	767	727	39	64	16
29)	510	66	19	46	17	427	396	381	14	27	4
30)	554	96	19	77	39	420	371	346	25	37	12
31)	195	—	—	—	—	195	134	184	—	8	3
Percent male											
1)	60.98	68.61	82.9	64.93	17.55	69.40	68.82	67.81	79.93	26.98	50.39
9)	61.23	45.96	96.55	34.85	17.65	65.94	70.18	69.33	82.67	18.67	25.00
12)	70.68	57.50	100.00	43.33	23.53	73.25	76.92	76.12	83.87	20.69	28.57
14)	73.23	75.00	100.00	70.00	22.22	75.73	78.95	77.65	81.82	40.00	50.00
15)	74.83	62.50	100.00	60.00	25.00	77.10	79.20	79.13	80.00	16.67	—
16)	53.14	20.00	100.00	92.31	—	56.96	62.68	61.31	80.00	7.69	—
17)	80.39	100.00	100.00	100.00	—	80.81	84.04	83.52	100.00	25.00	—
Percent female											
1)	39.03	31.39	16.58	35.07	82.28	34.60	31.20	32.16	20.07	73.02	49.61
9)	38.77	54.04	3.45	65.15	82.35	34.06	29.72	30.67	17.33	81.33	75.00
12)	29.15	42.50	—	56.66	82.35	26.75	23.27	23.67	16.13	79.31	71.43
14)	26.77	18.70	—	30.00	77.78	23.30	21.05	21.18	18.18	60.00	50.00
15)	25.17	25.00	—	40.00	100.00	23.66	20.00	20.87	10.00	66.67	100.00
16)	46.29	80.00	—	7.69	100.00	43.04	37.32	38.69	20.00	92.31	66.67
17)	18.63	—	—	—	100.00	18.18	15.96	16.48	—	75.00	100.00

1) All industries
2) Agriculture and forestry
3) Agriculture
4) Forestry and hunting
5) Nonagriculture industries
6) Fisheries and aquaculture
7) Mining
8) Construction
9) Manufacturing
10) Textile mill products
11) Chemical and related products
12) Metal and machinery
13) Iron, steel and non-ferrous metal industries
14) Fabricated metal products
15) Machinery, weapons, and precision machine
16) Electrical machinery, equipment and supplies
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25) Transport, communication, electricity, gas, water, steam and hot water supply
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27) Electricity, gas, water, steam and hot water supply
28) Services
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31) Government

SOURCE: "Annual Report of the Labour Force Survey," Statistics Bureau, Office of the Prime Minister, Japan, 1983.

Chapter 5

The Effects of Programmable Automation on the Work Environment

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Chapter 5

The Effects of Programmable Automation on the Work Environment

Summary

A number of factors determine the impacts of programmable automation (PA) on the work environment, such as how the technologies are designed and applied, the strategies employed to introduce them, and management's goals for automating. In general, the introduction of PA tends to improve the work environment. However, it has the potential to create new situations that are stressful or monotonous, resulting in negative psychological effects on the work force. PA offers a wide range of choices concerning its use—choices that, if made well, will help to ensure that PA is applied in ways that will maximize its potential for affecting the workplace positively.

Nothing inherent in automated technology makes a particular form of work organization "imperative"; PA affords many ways of organizing work and designing jobs. For this reason, it is possible to design and apply technology so that it will enhance, rather than detract from, the work environment, and to search for ways to design jobs that are compatible with both technology and the humanization of work. The search for such compatibility will be complicated by the potential tradeoff between conventional concepts of production efficiency and more complex concepts of worker satisfaction. There is some, but limited, evidence that using PA to organize work in ways that would enhance the work environment would lead to increased overall efficiency and a more motivated work force.

In the firms visited for the OTA work environment case studies, the implementation of PA made some jobs, such as maintenance, more challenging, and some, such as spot welding, less physically taxing. Other jobs, such as operating a numerically controlled (NC) machine, were less challenging when compared with operating conventional machine tools. Some jobs had high levels of stress due to the nature of the equipment (i.e., complex, highly integrated, and expensive), and to the relative lack of worker autonomy in controlling the content and pace of work.

Labor-management relations play an important role in the introduction of new technology. Using collective bargaining, organizing, and political strategies, unions in the United States have attempted to minimize what are perceived to be the socially harmful effects of new technologies on the labor force. Their efforts have generally been directed toward easing the adjustment process rather than retarding the process of change. Japan and many Western European countries rely on a number of government and organized labor mechanisms for dealing with the introduction of new technology and its effects on the workplace.

Introduction

Programmable automation has the potential to enhance the work environment in manufacturing. It will do so if it reduces the need for workers to undertake hazardous or unpleasant tasks and is applied in ways that provide variety and opportunities for decisionmaking in the workplace. As work becomes increasingly automated, it is important to consider the role people will play relative to equipment, and how we as a society will define and oversee that role.

The purpose of this chapter is to describe some of the effects on the manufacturing work environment arising from the introduction and use of PA, and to discuss some of the ways in which workers are likely to be affected—physically and psychologically. The approach is different from that usually taken in discussing PA technologies, their benefits, and their costs. While acknowledging the economic and technical issues surrounding PA development and use, the chapter focuses on the experiences and concerns of the people working with the technologies daily. These concerns seldom emerge in studies of R&D and industry characteristics, but they suggest additional social costs and benefits beyond the more obvious ones associated with changes in the number and types of jobs.

Attention to how PA affects the work environment may gain new urgency in the future due to reduced job mobility in manufacturing. As chapter 4 suggests, workers who are unhappy about their working conditions in the wake of new technology may have less freedom to change jobs because of reductions in production employment, changes in the occupational mix, and other developments constraining job opportunities. If the potential for job mobility decreases, the characteristics of remaining and new manufacturing jobs will become increasingly important, creating new imperatives for developing the potential capabilities of the technology to improve the work environment.

Background

The effects of PA on the manufacturing work environment in the United States must be considered within the context of traditional views of technological change. The apprehension surrounding technological progress and its potential to change the fabric of society is not new. What is different about current attitudes concerning new technology is directly related to its flexibility, its diverse applications, the large numbers of people that will be affected, and the social and political climate in which it is being introduced.

As early as the mid-1850's, America was viewed by Europeans as a country that eagerly and easily embraced technology as a replacement for manual labor. This was in stark contrast to the open resistance to industrial progress experienced in Europe. The American capacity for rapid innovation was variously attributed to such diverse factors as its public education system, a scarcity of labor, its democratic institutions, its utilitarian attitudes, an abundance of natural resources, and the enterprising spirit of its citizens.[1]

However, contrary to this idyllic view of American industrial progress as perceived by foreign visitors, historians record that even in the 1850's, technological change in the United States did not occur without very substantial costs to its citizens. For example, the work lives of skilled craftsmen were changed greatly through adjustment to the new requirements of industrialization, such as increased regimentation and less individuality. Unskilled workers were also affected adversely, since their skills were interchangeable and there were thus fewer opportunities for wage increases and other benefits.[2]

In the late 19th century, the principles of scientific management proposed by Frederick

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[1] Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca and London: Cornell University Press, 1977).

[2] Ibid.

W. Taylor attempted to rationalize the production process by determining the "one best way" to do a job.* In addition, these principles helped to form the view that efficiency depends on the degree to which management controls both the production process and the workers. In many manufacturing settings, vestiges of Taylorism still exist in a top-down style of management control characterized by rigidly defined tasks, attempts to minimize errors through increased automation, and minimal worker involvement in workplace decisions.

Today, it is generally recognized that technological developments tend to continually outpace the capacity of individuals and social systems to adapt.[3] This period of adjustment may be characterized by considerable tension between management and labor.

One of the principal benefits of computerized manufacturing technology is that it offers a wide range of choices for system design and implementation. With respect to the problems encountered in earlier technological change, one author commented:

> The changes and disruptions that an evolving technology repeatedly caused in modern life were accepted as givens or inevitable simply because no one bothered to ask whether there were other possibilities.[4]

The very flexibility of PA provides a range of choice, not only in the equipment configuration, but also in the organization and management of production. As stated by a contemporary British researcher:

> We are not compelled to follow the path we have followed so long, of subordinating work to the machine, and fragmenting it, until the best thing we can do with the jobs that remain is to automate them out of existence. We can if we wish provide a path through which human skill is preserved, . . . by evolving into new skills in relation to new machines.[5]

While the design of a machine or system establishes a basis for its effects on the work environment, the specific circumstances in which the technology is introduced also play a crucial role in shaping the environment of the automated workplace. In practice, the impact of a programmable system is influenced by an array of "environmental" factors, such as managerial goals, the age and physical layout of facilities, the types of technology already in use, the ways in which work has been (and will be) organized, management policies and practices, the attitudes of workers, interpersonal relationships, and the character of labor-management relations. This context, together with the technical capabilities and actual performance of the new system, determines the effect of computerized automation on the work environment.

The choices made for system design and implementation reflect value judgments. The minimal attention devoted to work environment issues in this country reflects the view that production efficiency is a function of equipment design and selection, and a judgment that worker attitudes are secondary at best. On a more basic level, value judgments pertaining to workplace issues reflect a disparity in available evidence. It is relatively easy to measure the performance characteristics of a machine; it is difficult to measure reliably the effects of equipment designs and configurations on worker attitudes and related changes in productivity. The difficulty increases as the organization of production changes to accommodate new processes and products. Such organizational changes are central to the success of PA; they also distinguish the work environment effects of PA from those of more incremental changes in manufacturing technology.

How workers are affected by automation depends very much on their individual personalities, expectations, and needs; it is therefore difficult to generalize about what is a "good" work environment for the introduction of PA. As one author recently pointed out:

---

*Frederick W. Taylor (1856-1915) revolutionized American factory production with his time-and-motion studies. This standardization of tasks, known as Taylorism, left workers with little or no opportunity to exercise either control or judgment over their work or workplace.

[3] See, for example, Langdon Winner, *Autonomous Technology* (Cambridge, Mass.: The MIT Press, 1977).

[4] Winner, op. cit.

[5] H. H. Rosenbrock, "Robots and People," *Measurement and Control*, vol. 15, March 1982, p. 112.

> Workers are not all alike; they have different needs, interests and motivations. Moreover, these characteristics constantly change over the career of each worker, ...[6]

However, there are some characteristics that are generally recognized as having a positive effect on the work environment. Among them are fair wages and benefits, job security, a clean and safe workplace, interesting work, some control over the pace of work, the ability to make decisions concerning how work is performed, recognition for work done well, opportunities for personal growth and advancement, and good relationships with peers and supervisors.

Recognizing some of the important characteristics of a positive work environment, and recognizing that these can help to alleviate the tensions of a rapidly changing workplace, new technology can be utilized in ways that facilitate a harmonious interaction between people and machines. Achieving such harmony is the goal of interdisciplinary research in so-called sociotechnical systems. The literature on sociotechnical systems discusses ways of designing jobs and changing work methods to consider both the social system of the work environment and the technical system of production simultaneously in order to optimize the relationship between the two.[7]

It is possible to design and apply technology so that it will enhance the work environment, and to explore ways of designing jobs that accommodate both the technology and the needs of workers. The challenge is to introduce new technologies in ways that consider the economic and social impacts more equally. However, there are conflicting interests involved in considering simultaneously the economic, social, and technical aspects of new technology. One recent study of the impact of microelectronics on the workplace concluded:

> It is not yet clear just what are the economic costs of careful, or socially acceptable, applications of the chip. Nor is it obvious that the normal market forces, or union pressures, will bring out the best in microelectronics for society.[8]

Okun has suggested that pursuit of an efficient economy creates inequalities, and society faces a tradeoff between equality and efficiency. If both are valued, and neither takes absolute priority over the other, then compromises ought to be made in places where they conflict.[9] In the case of the effects of PA on the work environment, the failure to balance both social and economic questions as part of the overall decision to automate will mean that the potential for PA to improve working life will not be realized. In the short term, only the economic costs of considering the social aspects may be recognized; over the long term, however, the cost of an unhappy worker may be realized as lower productivity. The concern extends beyond the individual PA user into a potential social services problem that could eventually affect whole communities.

The remainder of the chapter is divided into three sections. The first describes four OTA case studies of PA in selected manufacturing environments and discusses the principal themes that emerged from these studies. The next section discusses some of the impacts of PA on different aspects of the work environment, incorporating material from the case studies where it exemplifies these impacts. The final section provides an overview of approaches to work environment issues in Japan, Norway, Sweden, and West Germany and the experiences of these countries with the implementation of new technologies.

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[6] James O'Toole, *Making America Work, Productivity and Responsibility* (New York: Continuum, 1981).

[7] William A. Pasmore and John J. Sherwood (eds.), *Sociotechnical Systems: A Sourcebook* (La Jolla, Calif.: University Associates, Inc., 1978).

[8] *The Impact of Chip Technology on Conditions and Quality of Work, Worldwide Search and Examination of Evidence and Influential Opinion*, Report No. 1144, Ministry of Social Affairs and Employment, The Hague, 1982, p. 2.

[9] Arthur M. Okun, *Equality and Efficiency: The Big Tradeoff* (Washington, D.C.: The Brookings Institution, 1975).

OTA Work Environment Case Studies

In order to investigate the impact of PA on actual work environments in manufacturing settings, four case studies were conducted in companies that are leading users of PA—one each in the automobile, aircraft, and agricultural implements industries, and one encompassing a group of seven small metalworking shops. The three large companies studied were selected out of a list of approximately 30 firms that was compiled in consultation with a number of leading trade associations. The small metalworking shops were chosen after discussions with knowledgeable individuals and organizations in New England, the geographic region selected. While the companies are all advanced PA users, they differ in several important respects, including company size, product batch size, union representation, financial health, current level of market demand, and geography (see tables 48 and 49).*

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*None of the participating companies is identified by name. One of the companies requested this courtesy, and OTA decided to follow it throughout.

Table 48.—Characteristics of Small Metalworking Shops Studied by OTA

	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	Eta
Total employees	75	19	74	16	10	200	48
Employees on shop floor	60	16	60	15	6	130	40
Annual sales	$8.2M	$900,000	$4.5M	$600,000	$300,000	$25M	$2.75M
NC and CNC machine tools	21 NC and CNC	2 CNC lathes 1 CNC miller 16 NC millers	3 CNC punch presses 1 CNC laser cutter 5 CNC press brakes	6 CNC	4 CNC millers 1 CNC lathe	12 CNC lathes 2 CNC vertical millers 30 NC machines	21 NC and CNC machines; more than half of these are CNC; 2 CNC in prototype
Year company founded	1969	1940	1973	1972	1974	1945	1942
Year first NC or CNC machine tool purchased	1974	1966	1976	1976	1979	1957	ca. 1966
Principal client industries	Military aircraft, medical	Varied: electronics, hydraulics, etc.	Mostly electronics	Electronics, aircraft	Aircraft, medical	Aircraft, both military & commercial	Electronics, aircraft
Programing system	Digital "APT"	Genesis "Encode"	Webber "Prompt"	Webber "Prompt"	Bridgeport "Easy Cam"	Digital "APT"	General Numeric "Numeridex"
Age of programing system	3-4 years	6 years	3 years	6 months	2 months	11 years	1 year
Lot size range[a]	10-150	25-1,000	10-2,500	100-5,000	50-1,000	1-1,000	1-100
Average or typical lot size[a]	50	250-500	100	250-500	250	100	50
Employment level over time	Steady growth	Stable for 10 years, before that steady growth	Steady growth	Fluctuates, down from a peak of 19 in 1980	Growth, recent layoffs	Cyclical, twice as many employees in late 1960's. Constant for last 7 years	Stable
Size of shop in square feet	23,000	10,000	30,000	8,000	2,500	66,000	28,000

[a] Lot size figures are rough estimates only.

SOURCE: Office of Technology Assessment (data current as of April 1983).

Table 49.—General Characteristics of Manufacturing Firms Studied by OTA

	Small shops	Agricultural implements	Commercial aircraft	Auto
Batch size	Small, one of a kind	Medium	Medium	Large
Company size	10-200	Components plant—10,000 at capacity Tractor assembly—2,500	40,000 in commercial aircraft division 630 in NC machine shop	Plant employs 4,000
Sales market share	300,000 to 25 million	Company agricultural equipment sales over $4 billion in 1981; dropped in 1982, but share of farm equipment market climbed	Company claimed 56% of the market in 1981; in 1982, 48%	Company sales over $10 million in 1982
Unionized	No	Yes	Yes	Yes
Financial health	Good	Dominant in industry	Dominant in industry	Improving over recent times
Market demand	Tends to fluctuate with demand for clients' products	Slack	Slack; operating at 50% of capacity	Recently picked up
Geography	Within an hour of major industrial center in the East	Small, Midwestern city	Medium-sized west coast city	Within hour of major industrial center in East

SOURCE: Office of Technology Assessment (data current as of April 1983)

Six technologies were studied—numerical control (NC), flexible manufacturing systems (FMS), management information systems, automated materials handling, robots, and computer-aided design (CAD).* NC machine tools receive particular attention in the case studies because they are among the oldest modern examples of the application of digital technology to manufacturing, dating from the early 1950's. As such, NC represents the backbone of computerized production equipment, and is the most important application to date of computers in small and medium batch machining. In addition, although other programmable technologies may monitor the activities of workers or replace the worker entirely, NC machine tools continue to require the presence of an operator and significantly change the character of the person-machine interaction. The changes seen in the NC operator's job have implications for other situations in which the introduction of PA may change the nature of the interaction between person and machine. Thus, the work environment experience with NC may provide paradigms for other PA, including flexible manufacturing systems as well as nonproduction PA technologies.

The case studies are based on 3- to 8-day visits by two researchers to the three large companies, and 1-day visits to each of the seven small machine shops. The aim of the case studies was to identify qualitatively some of the important ways in which PA is currently affecting the work environment in selected sites; quantitative analysis was not feasible given the small number and the diversity of observations.* (See app. 5A for method of study.) A brief summary of each of the four case studies follows; a section is included describing the principal themes that emerged.*

---

*As was discussed in ch. 3, FMSs integrate NC and other PA technologies into a larger computer-controlled system that is the prototype of the automatic factory. Management information systems collect, transmit, and process data in a way that provides more comprehensive and immediate information to management about operations in both batch and mass production industries. Robots represent a versatile technology that can be used in a wide range of production settings either as stand-alone machines or as part of a larger system. CAD exemplifies the use of computers to transform the design process and the organization of the production process.

*The sample of people interviewed was relatively small and nonrandom, and the interviews explored a variety of issues within a defined range, rather than following a rigid format.

Case 1—Small Metalworking Shops

This case study investigates the introduction and use of numerical control in seven small metalworking shops—six machining shops and a sheet metal fabrication shop (see table 48). All of the shops work under contract to other companies (mainly aerospace, electronics, and defense industries), and have no commercial product of their own. The central production technology in these plants is NC, currently one of the most mature and sophisticated of the PA technologies, in which a preprogramed code directs the operation of a machine tool by means of a controller. Generally, these machine instructions, or "part programs," are prepared remotely by a part programer. Computerized numerical control, a refinement of NC that was developed in the mid-1970's, links a computer to the machine controller. This technical change brings about new organizational possibilities because the machine instructions can now be altered (edited), or even prepared, at the machine itself.

NC has a number of technical advantages over conventional equipment—e.g., easier machining of complex parts, repeatability, fewer fixtures and setups, and increased flow of production. In addition to these advantages, managers also cited two other motivations for installing NC equipment. One motivation was to respond to the perceived shortage of qualified machinists by providing the ability to transfer skills from the shop floor to a part program, hence depressing the level of skill actually needed to operate the machine. The second motivation for acquiring NC was to gain better control over shop operations. The predictability of the technology led to more accurate production cost estimates when bidding for new jobs and more reliable estimates of delivery times.

Case Study Conclusions

By reorganizing production in such a way as to centralize control and reduce the overall skill requirements of the shop, these owners have brought about changes in the work environment that substantially reduce the attractiveness of machining jobs, especially for skilled machinists. In general, less experienced workers and those whose previous work experience was largely on NC preferred NC, while workers with high levels of skill and extensive backgrounds on conventional equipment did not like NC machines unless they had become involved in programing. When the planning function is removed from the shop floor and transferred to a programer, machining work is transformed in such a way as to be unattractive to the most skilled members of the work force —although the usefulness of high skill levels was still emphasized by most of the shopowners interviewed. While reducing machinist intervention in the production process helps to guarantee that a minimum standard of quality will be met, it also limits the ingenuity and skill that might help to achieve a higher standard of quality. If the input of the person closest to the production process is substantially reduced or even eliminated, the loss in terms of the quality of production could be sizable, particularly when a skilled worker is operating the machine.

Based on the sample of small shops visited, four strategies that would enhance the work environment appeared technically feasible and desirable from the point of view of workers on the shop floor:

1. Programing of machines by their operators, except in cases where there are compelling technical reasons for doing otherwise (e.g., some programs are very complex, and writing them may require several hours of careful expert attention, away from the distractions of the shop floor).
2. Increased control over the editing of programs by machinists who are at the machine, watching the execution of the program.

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*The contractor report, "Automation and the Workplace: Case Studies on the Introduction of Programmable Automation in Manufacturing," will be available subsequent to publication of this report.

3. Training in programing for machinists, including rotation of machinists through the shop's programing department.
4. Training in machining that includes substantial work on conventional machine tools, and periodic rotation onto conventional machines to provide more challenge and variety.

Each of these changes that would enhance the quality of the work environment was present in an embryonic form in one or more of the seven shops studied. They are thus clearly technically feasible, since they have already taken place in a very limited way. They may also, in some cases, result in greater productivity. But it is also true that after a certain point, increases in shop floor autonomy with a view to improving the work environment tend to conflict with the shopowner's preferences for managing the business. At that point, further improvements in the work environment come at the expense of centralized control, which may also have implications for production quality. The issue of control, of course, is not peculiar to computerized automation in manufacturing settings; it represents one of the traditional workplace struggles between management and labor.

Case 2—Agricultural Equipment

Beginning in the early 1970's, the company, a midwestern manufacturer of agricultural implements and construction equipment, began to install a wide variety of computer-based systems in one of its principal businesses, the manufacture of tractors. Today, the company is regarded as one of the leading users of PA in medium-batch manufacturing. This case study focuses on two of the company's plants that have been widely recognized as pioneering automation efforts—the components plant and the nearby tractor assembly plant. Three major systems were selected for examination: 1) a management information system, particularly a labor reporting subsystem; 2) the automated materials handling system in the tractor assembly plant; and 3) the flexible manufacturing system in the manufacturing plant.

From management's point of view, PA has been vital to the company's success in an increasingly competitive industry. The technology has resulted in increased flexibility to respond to rapidly shifting market conditions, better product quality, and higher productivity. An important factor contributing to productivity improvement has been the transformation of what management saw as a series of difficult-to-control, stop-and-go operations into a more tightly controlled, centrally directed "even flow" of parts, suggestive of operations in continuous-process industries.

Case Study Conclusions

The effects of increased automation on the work environment seen in this case study fall into four broad categories. The first covers effects that are the intended result of management's desire for flexibility, rapid response, and closer managerial control of operations. For example, the ability of the company to track parts through the production process makes shop floor operations increasingly visible to middle- and upper-level managers, facilitating scheduling and making it increasingly possible to dictate the details of production from a high level in the organization. This decreases autonomy for supervisors by limiting their range of choices in certain scheduling and personnel matters.

The second category of effects on the work environment stems from the implementation process, broadly construed. For example, the disruption caused by downtime and scheduling irregularities resulting from the implementation and debugging process for highly complex and integrated computerized systems can degrade the work environment. The persistence of such problems over a period of years, not just months, raises the possibility that the debugging of one or another system could become a fact of life—and of the work environment—at technologically advanced companies. Workers at this site were particularly affected by frequent downtime because of their incentive pay system.* This system helps to create a highly motivated work force, and employees covered by the incentive pay system may use considerable ingenuity to keep machines running. Machine downtime is not welcomed by incentive workers, and most of the workers interviewed expressed intense frustration with automated systems that frequently broke down.

A third category of effects on the work environment is brought about by the complexity and highly integrated character of the capital-intensive installations. Maintenance workers found their work on a computerized system exciting and challenging (according to one electrician: "This new technology is scary as hell, but I love it"). However, the combined effect of the high cost of the system and the "domino effect" of a machine or system failure created considerable pressure as well. The integrated nature of the operation made the failure of any machine linked to the larger system a more serious problem than the failure of a stand-alone machine would have been. Additionally, most electricians interviewed felt that the diagnostics now required more skill than previously; however, the repairs were often easier, particularly when they only involved changing a circuit board. Under these conditions, collaboration increased among repairers and among different skilled trades.

The final category includes effects that result from system designs that attempt (with varying degrees of success) to minimize the necessity for operator intervention. One of the problems mentioned most frequently by operators of flexible manufacturing systems—as well as by maintenance workers on other highly integrated and expensive systems—is the alternating boredom and pressure that characterize their jobs. The FMS clearly required some operator input, yet it had not been designed to adequately acknowledge and accommodate that input; in addition, operator training may not have been sufficient.

Case 3—Commercial Aircraft

The manufacturer of commercial aircraft that is the subject of this case study is a division of a larger aerospace corporation. Both the division and its parent are widely regarded as being at the cutting edge of both product and process innovation in the aerospace industry. The case study has a dual focus: first, it explores the use of computer technology to revolutionize the organization of work, principally in the design and engineering of the airplane; then it looks at NC machining in a large production machine shop. Since the NC machine shop is a production terminus of a stream of data that flows from design to the manufacture of a part, it is directly affected by the organizational changes that are taking place

The company's use of CAD has resulted in a number of important benefits: 1) elimination of routine work, 2) assured access to the most up-to-date design, 3) reduction in errors, and 4) the ability to revise designs more frequently and to experiment more fully with design alternatives. A central thrust is to link the separate design, business, and manufacturing computer systems into a centrally directed, integrated whole, and to thus move design decisions to a higher level in the organization. The goal is to create a controllable "stream" of information governing the development and production of the airplane from the point at which the airplane is initially designed to the point at which it first lifts off the runway.

As in the case study of the small metalworking shops, the use of NC has made it possible to remove from the shop floor much of the decisionmaking involved in part production, taking away a substantial amount of discretion from those involved at the point of production, and relocating it earlier in the design to build process. Many of these decisions are now made by programers; however, the operator retains the critical control over the speeds and feeds at the machine.

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*This system combines a standard base rate with a bonus for production above the standard rate. An operator working at "incentive pace" earns about 130 percent of the "standard" base pay. The company aims to have production workers eligible for incentive pay about 85 percent of the time, the remaining 15 percent being set aside for "inherent delay," which includes those parts of a job whose pace is out of the control of the worker. During periods of inherent delay and downtime the worker is paid the standard rate. The introduction of automation can influence incentive pay in two ways: 1) by requiring determination of new incentive standards, and 2) by changing the proportion of inherent delay and downtime on the job.

Case Study Conclusions

The company goal to use CAD to establish a stream of shared data has significant implications for the work environment. For example, the jobs of engineers at earlier points in the design process will become broader and more challenging; but there will be proportionately less opportunity for creative work by engineers at later points in the design process. While this may be beneficial for the aircraft design process overall (in particular, because of the special concern for quality and reliability of aircraft, relative to other goods), it is likely to have a negative effect on middle-level workers who have been accustomed to more challenging work. Considerable amounts of routine data-handling will be eliminated by the establishment of shared data requirements and the automation of data transmission between groups. In addition, there will be increased interdependence among various groups and functions within the company as each group spends more of its time working with shared data.

Use of NC has a number of effects on the work environment of machinists at this site. NC has not eliminated the need for a skilled operator, since skill is still required in the form of alert supervision of the machine (rather than continuous active intervention); yet the removal of a substantial part of the traditional machining work makes it more difficult for the operator to remain engaged in the cutting process. The amount of latitude that NC machinists have in the performance of their duties is significantly reduced if all but the most routine programing is removed from the shop floor; this is a major factor in the boredom reported by operators.

The study found that interdependence has increased in the machine shop, since there are more support groups, e.g., programers, involved in the production of any given part. This means that a delay in any one area affects the operator's ability to produce parts quickly and efficiently. The case study also found that the ability to dictate exactly how the machinist's job will be done makes it possible for management to track an individual's performance more closely. In addition, an electronic system makes certain aspects of shop floor operations more visible to management. The system enables a machinist to page a support group member and also monitors production at the 66 NC machines.

Case 4—The Auto Company

This case study examines the application of robots to spot-welding operations in an auto company's assembly plant. In 1980, in response to the increase in consumer demand for small cars, the company designed a new model that required a $60 million retooling at the plant visited. The bulk of the retooling took place in the framing side of the body shop, where sheet metal parts of the car are welded together. In selecting machinery for its new welding facilities, the company chose a system that provides what is perhaps the most advanced frame welding technology available. It involves a single fixture or "gate" that holds the sides, underbody, and other parts in place while eight robots apply spot-welds that set the dimensions of the body. Most of the other robots in the plant apply "re-spot" welds which increase the mechanical strength of the car.

The automated area consists of two major components: 1) the subassembly areas where parts of the sides and underbody are welded together; and 2) the "main frame" line where the sides, roof, and underbody are welded by the robotic system and re-spot robots to form the complete car body. The case study focused on the side aperture area where parts are welded together to make the right and left sides of the car, and on the main frame line. Sixty-four robots are located in these areas.

The robotic system has a number of major technical and economic advantages over previous methods of welding: 1) the dimensional consistency of the body is assured because only a single gate is used for each car type; 2) the strength and quality of welded frames are improved because there are fewer missed welds, and the welds are placed identically in each body; and 3) subsequent retooling costs are substantially reduced by decreasing the number of gates and clamps that have to be purchased for each model.

Case Study Conclusions

Two important specific benefits resulting primarily from automation were observed. The first was that robots have eliminated a number of physically demanding hand-welding jobs that required operators to work in the midst of sparks thrown off each time a weld was made. The second benefit is that automation has substantially increased the breadth, challenge, and interest of maintenance positions. To some extent, welder repairmen have taken on responsibilities traditionally handled by basic tradesmen in that they maintain a wide range of electrical, hydraulic, and robotic equipment, and they also program the robots. The corporate director of manufacturing engineering regards welder repairmen as an important part of the company's move to increase productivity through combining job classifications.

However, the work environment has deteriorated significantly for many production workers and supervisors. An intensification of work and an erosion of the quality of life on the job for production workers in the body shop stem from the fact that subassembly jobs are now tied to a line. By tying subassembly work to a rhythm over which the worker has no control, the automated system has eliminated the principal feature of off-line jobs that made them more attractive than line jobs. Downtime on the automated system creates stop-and-go pacing that is beyond the worker's control; it also creates a situation where the subassembly and main frame lines are run faster in order to keep up with the rest of the plant. For repair supervisors, the responsibility for maintaining operation of the complex, highly integrated production system creates great stress.

It is important to note that these problems arise not from automation or the introduction of robots per se, but rather from the system design and operating practices. Two aspects of the design are especially important: the arrangement of successive subassembly operations in series, and the restriction of space for storing parts between these operations. The design decisions are complemented by the operating practice of storing even fewer parts between subassembly operations than space allows. By minimizing such "banks," management believes it can assure a steadier, higher quality, and more efficient production flow.

Case Study Themes

At every company studied, a common theme emerged: establishing more effective managerial control over the activities of the enterprise. In the firms that produced parts in small and medium batch sizes, PA was the centerpiece of a strategy to establish a more managerially directed flow of parts through production, in some cases approximating the even flow of continuous-process industries. At the automaker, where the mass production of parts has been carried out for years on a moving assembly line, the company sought to extend this flow to the remaining off-line areas of the welding operation.

The aircraft company also sought to streamline the flow of information through design and engineering. In addition, it wanted to move decisionmaking to as early a point in the design and manufacture of the airplane as possible. An important corollary of these changes was minimizing human input. This extension of control in design and production, in management's view, makes possible a better coordination and a more efficient use of the firm's resources. These organizational choices, however, have important consequences for the work environment.

Because of the great variety of computer-based technologies, as well as the wide variation among companies in terms of the environmental context into which these technologies are placed, the findings of the four case studies do not suggest any one generalized impact of PA on the work environment. Instead, some overall themes emerged to varying degrees from the different companies studied:

- *Changes in skill requirements and occupational structure.*—There was a tendency to embody skill in machines or to move skill to an earlier point in the design and manufacturing process. In occupations such as highly skilled machining this meant that fewer skills would be required on the job. Maintenance work, however, tended to require more skills.
- *Training.*—Some operators and maintenance workers expressed a strong desire for more training that would allow them more effectively to run or to repair the machines to which they were assigned.
- *Increased interdependence.*—The introduction of PA brought about a greater interdependence among production workers, greater collaboration among maintenance workers, and the necessity for increased cooperation between production and maintenance workers.
- *Decreased autonomy.*—Computer-based automation is used in ways that result in decreased autonomy for workers, stemming from the removal of production decisions from the shop floor, the electronic monitoring of some work areas, and the attempt on the part of management to establish an even flow of parts through the plant and of information through the company.
- *Boredom.*—One of the consequences of systems intended to minimize operator intervention is that machines may run for longer, although not indefinite, periods of time without active intervention by the operator. For some machine operators, boredom on the job has become a widespread complaint. Some maintenance tasks, however, have become more challenging.
- *System downtime.*—Because of the complexity of programmable systems and their high level of integration, the effects of problems with any unreliable element of the system tend to spread, affecting the work pace of production workers and putting great pressure on those involved in the maintenance of the system. Downtime may decrease with better system design and more reliable components.
- *Stress.*—Two major sources of automation-related stress were identified: 1) working on very complicated, very expensive, and highly integrated systems; and 2) the lack of autonomy at work, extending in some cases to computerized monitoring by management.
- *Safety.*—Some applications of PA make the workplace safer, either by eliminating hazardous jobs altogether or by allowing the operator to stand farther from the machine during operation. Other applications introduce hazards of their own, such as automated carriers, clamps, and fixtures that move and close without direct human initiation and sometimes without warning. The net effect of PA, however, is a reduction in traditional physical hazards.
- *Cleaner and lighter physical work for operators.*—Some forms of PA have reduced or eliminated heavy or dirty work. In some cases, new jobs requiring physical labor are created in the place of the old, heavier jobs.
- *Job security.*—The combination of substantial layoffs at all the large companies and the widespread perception among workers that the introduction of computerized automation caused significant displacement raised strong apprehensions among workers.

Further information on these case study themes will be included in the following section concerning impacts on work environment, as well as in other chapters of the report where appropriate.

Work Environment Impacts

The OTA work environment case studies demonstrated some of the effects of various PA systems in selected environments. Some recurrent themes emerged regarding the nature of those effects. This section examines some of the broader work environment issues within the categories of organization and nature of work, changing skill levels, training, occupational safety and health, and labor-management relations.

Organization and Nature of Work

The ways in which work is organized, together with the specific design features of PA technology, will help to govern the effects on the work environment. In the short term, the new and emerging technologies will be adapted to traditional structures of work organization; over the long term, the structures will change to reflect the characteristics of the new technologies. While it is too early to predict how these changes will develop, the experience to date may offer some insights.

One of the most vivid examples of how the organization of work in automated manufacturing can affect the quality of the work environment comes from the allocation of programing in an NC shop, as demonstrated in the OTA case studies. The introduction of NC machinery is usually accompanied by the development of a new programing department and a new division of labor. The planning of work becomes more centralized and is moved off the shop floor, so that planning and execution become increasingly separated. From the point of view of management, this results in increased efficiency and control over the production process. However, whether or not production workers are permitted to edit programs on the shop floor, or in general engage in planning, can determine whether their jobs are routine and relatively boring or involve, instead, an element of challenge and decisionmaking. The assignment of work is a function of managerial choice, but it also reflects the nature of the product. For example, in aircraft manufacture, concerns for precision, reliability, and safety make control especially important. Other settings provide more latitude for worker discretion.

The organization of work in ways that remove creative decisionmaking from jobs does not only apply to production workers. It is also reflected in the changes projected for engineering jobs at the aircraft manufacturer as CAD is used more widely. The jobs done earlier in the design-build process will be broader and more technically detailed, while the need for engineering skills later in the process will be reduced. The result will be less autonomy and decreased opportunities to contribute to the production process in meaningful ways for engineers who are not performing the broad and creative jobs at the beginning of the design-build process. According to the director of the CAD/CAM Integration Team:

> Once the system is in place, most of the decisions are made; so you're taking away a lot of individual decisions . . . whoever's involved downstream is working in a lot more controlled environment than he has in the past.

It is generally agreed that there is nothing inherent in automated technology that makes a particular form of work organization "imperative."[10] For example, West German researchers describe an alternative job structure for a flexible manufacturing system, although its viability is yet to be proven long-term.[11] Under the proposed alternative, the staff is composed exclusively of skilled workers, such as specialists in machine tools. Some would have additional training in electronics. All or most of the nonmachining tasks required by the FMS could be performed by the operators, working

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[10] Joel A. Fadem, "Automation and Work Design in the U.S.: Case Studies of Quality of Working Life Impacts," published in *ILO International Comparative Study,* Federico Butera and Joseph Thurman (eds.) (Amsterdam: North Holland, 1984).

[11] Christoph Kohler and Rainer Schultz-Wild, "Flexible Manufacturing Systems—Manpower Problems and Policies," presented at the 1983 World Congress on the Human Aspects of Automation, Ann Arbor, Mich., August 1983.

Photo credit: Beloit Corp.

The dramatic change in the nature of engineering work is demonstrated in the three photographs above. (Top) pencil-and-paper operation at the turn of the century. (Middle) more recent paper-based engineering design. (Bottom) the manipulation of data through the use of computer-aided design in job rotation. Only some of the programing jobs and major repair and maintenance tasks would have to be carried out by personnel working outside the system. This system would provide considerable job variety for operators, in contrast to the more traditional hierarchical approach of combining workers who have a relatively low level of skills, and whose jobs are highly specialized, with one or two group leaders or foremen with special skills.

Research currently under way at the University of Manchester (England) is attempting to develop software that will enable the equipment operator to program an FMS by making the first batch of parts.[12] In this experiment, the human qualities of skill and judgment are not eliminated, but are assisted and made more productive. However, some experts have expressed some skepticism about this proposal. They suggest that it represents a cosmetic solution that would not work well in practice, since the situation would be the same for the operator after the first batch of parts was made unless the parts were changed frequently.

PA also has an effect on the nature of work. A striking feature of the many systems observed during the company visits that has consequences for the work environment is their high level of integration. This results in an increased interdependence among workers who deal with these systems. For production workers, this interdependence chiefly meant that at certain stages of production the input or participation of others was necessary, requiring teams rather than individuals to complete a job. For subassembly production workers in the auto body shop, interdependence increased because each individual was more closely tied into the pace of the system as a whole. One subassembly worker explained:

> Before, you had more individual operations . . . you might have, maybe, two people working together. Well, now you have maybe five, six, seven, eight . . . and everybody dependent on everybody.

The higher degree of integration results in more synchronous work for all production workers, making it impossible for individual operators to work faster or slower than others in the system for more than several minutes at a time.

On the FMS at the agricultural equipment company there was evidence of a greater need for equipment operators to coordinate with the system superintendent in the computer control room and with other operators. Even stand-alone NC operators, both at the aircraft manufacturer and at the small job shops, commented on their increased need to rely on programers and other support operations. No longer could a machinist execute an entire part alone, as was generally done on conventional machine tools. An NC operator at the aircraft company said:

> On a conventional machine it's pretty much just between you and the machine . . . . On the NC machine you've got the programer, . . . NC tooling, . . . planning, and if any one part of it breaks down, then the whole thing goes.

A supervisor in the same shop also felt the effects of this increased interdependence:

> Supervising NC, you have to deal with more support groups. You're more vulnerable to their preferences. There's more negotiation beforehand with people like programing and fixturing.

Maintenance workers experienced the increased interdependence in their work chiefly as an increase in the need for collaboration among the different skilled trades. The complexity of the new systems meant that, in many cases, diagnosis and repair required the input of workers with varying backgrounds. A skilled tradesman at the agricultural implement maker described the situation:

> You can save a lot of time by people working together and getting along. Otherwise a two-minute problem becomes a two-hour problem. A few years ago you could do it by

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[12] H. H. Rosenbrock, The University of Manchester Institute of Science and Technology, "A Flexible Manufacturing System in Which Operators Are Not Subordinate to Machines," a proposal approved by the Science and Engineering Research Council in 1983.

> yourself, but now you need two heads, one mechanical and one electrical, and a good operator.

There are opportunities for enlarging the scope of jobs with PA. The OTA case study on the seven small shops outlines a number of ways to improve job design for NC operators—including involving them in programing and editing, and providing opportunities for job rotation. With appropriate training, workers could be involved in a greater variety of tasks by rotating jobs; however, this would require cooperation between labor and management in agreeing to increased flexibility in work rules. Another opportunity for workers to perform a wide range of tasks rather than narrow, fragmented ones is in the application of group technology, through the use of manufacturing cells producing families of parts grouped on the basis of similar shapes and/or processing requirements.

The flexibility of PA provides the potential to achieve a better balance between the economic considerations that determine technological choices and the social consequences of those choices in the workplace. There are cases where organizational and technological changes have been combined successfully to yield dramatic improvements in productivity and effectiveness.[13] While these changes generally were motivated by factors other than improving the work environment, organizing work in ways that improve the work environment should result in economic payoffs as well through better worker morale and productivity.

Many of the concerns about the introduction of PA revolve around the changes it will bring about in the organization and nature of work. The choices made by those who design and manage automated systems will have a profound effect on how these systems influence the work environment.

Changing Skill Levels

Chapter 4 discussed the changes in skill levels and mixes that can be anticipated through the introduction of PA on a large scale. This section deals with work environment aspects of changing skills levels, including perspectives gained from the OTA case studies.

The ways in which work is organized and jobs are designed will determine both the skills needed to do a particular job and the overall level of skills required in a workplace using PA. In general, PA gives rise to a greater need for conceptual skills (e.g., programing) and a lesser need for motor skills (e.g., machining) than are required for conventional equipment.[14] Zuboff describes the new relationships between individuals and tasks that are created by information technology as "computer-mediated."[15] Computer-mediated work involves the electronic manipulation of symbols—an abstract activity rather than a sensual one. There will be a greater need for workers to monitor and maintain systems rather than to actually operate them, and more of the decisionmaking capability will be programed into the technology. For instance, NC machines have the potential to significantly lower skill requirements for operators, compared to conventional automation.

In the small machine shops visited for the OTA case studies, the owners all reported that the use of NC allowed them to run their machines productively using workers with less skill than would have been required on conventional equipment. The use of NC did not make machinists' skills superfluous, nor did it eliminate the need for some highly skilled workers in the shop, but it did allow the shop to function with a lower overall skill level in its work force than was previously possible. One shopowner commented:

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[13] Robert Zager and Michael P. Rosow (eds.), *The Innovative Organization: Productivity Programs in Action* (New York: Pergamon Press, 1982).

[14] Barry Wilkinson, *The Shopfloor Politics of New Technology* (London: Heinemann Educational Books, 1983).

[15] Shoshana Zuboff, "New Worlds of Computer-Mediated Work," *Harvard Business Review*, September-October 1982, pp. 144-45.

> Five, six years ago we were very dependent on skilled labor, to the point where I spent half my life on my hands and knees begging somebody to stay and do something. And they tended to be prima donnas: "I won't work Saturdays" and "I don't work nights." And this is one of the motivating factors in bringing in NC equipment. That reduced our dependency on skilled labor.

In situations where less overall skill is required the application of a higher level of skills will usually result in a more efficient operation. Even on a highly automated system, such as a flexible manufacturing system, human input remains important. The initiative and judgment that are occasionally required for optimum operation of such complex systems may not be present if skilled craftsmen and/or highly trained operators are not available.

The relative mix of skills required within the organization as a whole may change with the introduction of PA systems. This will vary among firms, depending on their products and processes. At the aircraft manufacturing firm, establishing a "data stream" would affect the company's skill requirements throughout its engineering operations. This would make the jobs done earlier in the design-build process broader and more technically detailed, while reducing the autonomy of engineers and the need for skills later in the process. This has advantages for the aircraft industry because of its particularly stringent needs for quality control. As described by a company official:

> A number of the people that are left will be an element of a very controlled process. The ingenuity of the craft will have been removed. The advantage is to have more consistent outcomes with the hiccups removed. People's actions will be more controlled by strict procedures. The human part of the job will be less evident.

At the same time, many relatively routine jobs would be eliminated. If accomplished, this would bring about a substantial reconfiguration of skill within the company, a reconfiguration that will not necessarily be obvious from a list of occupational titles.

At the body shop of the automaker, there has been a distinct rise in the ratio of skilled nonproduction workers to production workers. This is due to reductions in the number of production workers as well as increases in skilled maintenance labor.

Training

Chapter 6 discusses in detail the changes in education and training needs that will result from the widespread use of PA. This section provides perspectives that may go unrecognized in explicit education and training-oriented analyses and points to the fact that attitudes about training complement other attitudes and responses concerning new technology.

The OTA work environment case study interviews detected widespread concern among workers using automated equipment about what they perceived to be inadequate training, particularly for their present jobs. The chief complaints came from equipment operators and skilled trades people at the large companies visited. Some of the interest in training was motivated simply by curiosity about the new computerized technology. However, most often operators felt that their lack of training in the capabilities of their machines made them less productive workers.

Machinists in the NC shop at the aircraft company were the most vocal about their training needs. Although the company sponsored after-hours courses, the operators reported that these classes did not address the specific capabilities of their machines. NC operators were distressed about not knowing more about their machines; they felt that they could produce better parts if they were better versed in the use of their equipment. One machinist commented:

> It's like having a DC-3 pilot and walking him over to a 747 and saying, "Now look guy, it's an airplane, too—use it to the fullest extent it was made for . . . and if you don't know how to fly it, then check with the guy

in the right seat because he has probably been in it before and he will show you how the ropes work."

Some maintenance workers also complained about inadequate training. Maintenance personnel are expected to repair increasingly sophisticated and complex electromechanical equipment, and most of the maintenance workers interviewed felt inadequately prepared for this responsibility. Compounding their sense of inadequacy was the rate of technological change, which could quickly make even recently learned systems outdated, and the pressure they felt to repair the costly and complex technology in the minimum possible time.

Another force motivating workers' interest in further training is the fear of displacement as more and more jobs are affected by automation. The statement of an operator on the FMS, who had bid onto the system partly because of his concern about being left behind by changing technology, was typical—"If you don't get into it, you won't be able to get by. If you're looking at 15 years or so before retirement, you'll be sweeping floors."

The majority of the managers and machinists interviewed in the small shops believed that training on conventional equipment was an important prerequisite for effective performance on NC equipment. It was not clear whether they viewed the technical qualities of NC to be the principal drawback of learning machining on NC equipment only, or whether their concerns had to do with how NC machine operators are often trained (i.e., only on a single machine, not taught to plan work, set up, etc.). In the small shops, there were no complaints from workers about the adequacy of training. This may have been because the employees did not expect the employer to provide training, or perhaps because there was more informal training in small shops.

Occupational Safety and Health

The various forms of PA have both positive and negative effects on the safety and health of workers. In general, the introduction of PA tends to have a favorable impact on the work environment, although some new physical hazards associated with the lack of immediate worker control over system operations may emerge. However, PA will create new situations, or perpetuate old ones, that may have negative psychological effects on the work force.

Overall, the potential physical hazards appear to be more amenable to solution than some of the psychological ones because they are more easily recognized and are less subject to the subtleties of individual personalities. The relief of such symptoms as boredom and stress is more challenging because they are not as well measured or understood, affect different people in different ways, and are often complicated by other factors not directly related to the workplace. In addition, a commitment to alleviating monotony and stress in the workplace usually involves major changes in the way work is structured that can pose problems for both managers and other workers. These safety and health considerations are discussed below.

Effects of PA on the Workplace

Programmable automation has a variety of implications for health and safety in the workplace. For instance, robots are amenable to hazardous tasks in environments that are unpleasant and unhealthy for human workers. Thus, there can be a net positive effect on workers when a robot is installed for this purpose, providing the worker displaced is transferred to another job that is more pleasant or is trained to monitor or maintain the robot. A worker's lot is considerably improved when hard or dirty physical labor is assumed by a robot.

However, certain precautions are necessary to avoid unanticipated encounters between robots and humans. Statistics on such encounters in the United States are presently unavailable, although the Robotic Industries Association (formerly the Robot Institute of America) is planning to develop them. A recent Japanese Ministry of Labor survey indicated that in that country, since 1978, there had been 2 workers killed, 9 injured, and 37 "narrow escapes"; since near-accidents are not usually reported, the number of such incidents was presumed to be much higher.[16] As a result, the Ministry of Labor is currently drafting regulations dealing with robot safety. These regulations will make it mandatory to: 1) enclose robots with a protective screen or fence, 2) establish operating regulations with fail-safe on-off buttons and possibly auditory signals indicating the commencement of operation of mobile robots, and 3) install safety switches enabling immediate shut-down in case of emergency. Also being considered is specialized training on the safe operation of robots, as well as the provision of clearer operating instructions, including visual aids.

In response to concerns about robot safety, the Robotic Industries Association has organized a committee of robot producers to provide guidelines for the safe use of robots. In addition, major robot users in the United States, such as General Motors, Chrysler, and Ford Motor Co., apply their own sets of safety standards (see table 50). The National Institute for Occupational Safety and Health (NIOSH) has a planning project under way that will examine the potential health and safety problems associated with the introduction of robotics and define the need for further research. NIOSH is also developing guidelines on sensor-based methods to prevent fatalities and traumatic injuries during the maintenance of automated machines.

A recent report prepared by the British Machine Tool Trades Association described the potential hazards of robots and developed a method of assessing the risks.[17] According to this report, the major new hazard is the work envelope of the robot because it increases the complexity of guarding arrangements. Unpredictable action patterns, its ability to move in free space, and the possibility of reconfiguration all distinguish a robot from other automated equipment. The report refers to the following incidents of unpredicted robot movement which have occurred:

- aberrant behavior of a robot caused by a control system fault,
- jamming of a servo-valve,
- robot movement cutting its umbilical cord,
- splitting of a union on an exposed hydraulic pipe, and
- fault in data transmission causing a larger than anticipated movement of the robot arm.

In addition, the report discusses recommendations on design requirements and methods of safeguarding, including safe systems of work and rules for access to the robot. Advice

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[16] "Microelectronics and Its Impact on Labor," report of the Japanese Ministry of Labor, August 1983.

[17] "Safeguarding Industrial Robots: Part I, Basic Principles," a report of the Machine Tool Trades Association, London, England, 1982.

Table 50.—GM Robot Safety Standards: Suggested Safeguards

Safeguards	Unauthorized intrusion	Authorized		
		Teach	Maintenance	Side by side
Mechanical stops			X	X
Barriers	X			X
Lockout			X	
Limit detecting hardware				X
Software limits				X
Proximity detectors	X			X
Presence detectors	X			X
Vision optical systems	X			X
Robot deactivation		X	X	X
Slow speed, low power		X	X	X
Excess-flow check valve (hydraulic fuses)		X	X	
Emergency stop (readily accessible)		X	X	X
Warning methods	X			

SOURCE: General Motors Corp., Operations Safety and Health Manual, sec. 28, January 1983.

on control systems, programing, maintenance, and operation is included, together with a brief summary of the legal requirements as they currently apply in the United Kingdom.

In one manufacturing site visited by OTA staff, a number of safety precautions for working with an arc-welding robot were observed.* For instance, the robot is programed to work in sequence at two stations, allowing the operator to set up or clear one station while the robot works at the other. Pressure-sensitive floor pads prevent the robot from working at a station if a person is standing in a risky location. Also, a flashing yellow light indicates that the robot is on, and an alarm sounds when the robot has finished a task. In order for the robot to move from station to station, a relay switch must be pressed. The opening of a protective chain around the area will cause a circuit to be broken and the robot will stop.

In the auto company case study, the introduction of robot spot-welding removed auto production workers from the point of contact between weld gun and sheet metal, where showers of sparks were generated. However, it was generally agreed that the danger of injury has escalated for repairmen who work with equipment that cannot be pulled to one side and replaced by a backup, but must be repaired in place before operation can resume. Dangers stem from the complexity, unfamiliarity, and automatic nature of the new equipment that may move without direct human initiation and sometimes without warning. The auto company safety administrator commented:

> . . . .In the old days, you had one [weld] gun, and you could shut it down and work on it. Now you've got this complicated mess. If you don't know what you're doing, you could get hurt. . . . We've had press injuries you didn't have before, and automatic clamps.

Production workers who were interviewed in the auto plant believe that safety is poor in the automated system. Two problems in particular disturbed them—pools of hydraulic oil surrounding much of the automated machinery and the increased risk of cuts with the robotic welding system. The union committeeman claimed that the pressure to quickly refill the conveyors when part of subassembly suffers a breakdown leads to safety hazards:

> This [the need to catch up] is a real incentive for people to cut corners . . . to take chances. It's one of the reasons we do have a large number of lacerations. . . .

It is important to note in this case that, while breakdowns are technological in nature, the pressure to meet quotas in spite of equipment failure is organizational. This situation is not unique to PA, but the problem is exacerbated by a system designed in such a way that equipment cannot be pulled to one side for repair, and by the complexity and automatic nature of the equipment. In addition, the high capital cost of the equipment increases the desire to use it to the fullest extent. This may entail operating the line faster to make up for time when the machine is down, in order to meet production goals.

The potential safety and health hazards for workers using video display terminals (VDTs) for CAD are very different from those for workers using robots or other forms of PA on the shop floor. Both the work performed and the technology itself are substantially different. Although there is documentation of increased levels of stress among clerical workers using VDTs for long periods of time, the problems are lessened when the terminals are used as a tool to augment other activities, as in CAD, and when workers retain their autonomy and decisionmaking functions. Workers and worker representatives continue to be concerned about levels of radiation emitted by VDTs, although evidence to date suggests that the levels of radiation emitted by VDTs are too low to be hazardous to health.[18] Nevertheless, NIOSH is continuing research in this area. Eyestrain and postural problems are controllable to some extent through properly designed workstations, lighting, and frequent breaks.

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*OTA site visit, Emhart Corp.; United Shoe Manufacturing Plant, Beverly, Mass., June 1983.

[18] "Video Displays, Work and Vision," report of the National Research Council (Washington, D.C.: National Academy Press, 1983).

Based on the technologies observed for the OTA work environment case studies, the field record of PA with respect to safety appears to be mixed, which is to be expected with relatively new technologies. On the one hand, some types of automation remove production workers from close contact with tools during actual operation. Three different field examples suggest that automation can improve safety by increasing the distance between workers and the part being machined, assembled, or processed: 1) the introduction of robot welding removes workers from the point of contact between the weld gun and sheet metal; 2) machinists on NC equipment work at a greater distance from cutting tools and often are separated by doors and enclosures; and 3) at the agricultural implements firm, robots rather than workers now spray-paint tractors in an atmosphere filled with fumes.

On the other hand, it was noted that automated carriers, clamps, and fixtures move and close without direct human initiation and sometimes without warning. This can be particularly dangerous where adequate precautions are absent and in highly pressured settings, e.g., for maintenance workers who deal with complex equipment on an assembly or processing line that cannot start again until they finish repair work. One worker at the agricultural implements firm noted:

> I've seen the thing move and nobody touched a button. You're dealing with something you can't control. It's created a whole different type of problem—not necessarily more problems—but different problems.

Working around complex machinery that can move in several different directions according to a plan that is not under the control of an operator or repair person—and may not even be well understood by those in the immediate area—was mentioned by workers as a significant safety hazard. The level of complexity on programmable systems may make it difficult for a worker to anticipate the system's behavior and avoid the risk presented by sudden and unpredictable motion. This was demonstrated in 1979 in Michigan when a worker was killed when hit in the head by a "robot arm." The worker was attempting to climb a storage rack to get parts because a materials handling system designed to fetch parts automatically had been malfunctioning. Since the arm operated silently, the worker was unaware it had resumed activity.[19]

Nevertheless, with appropriate precautions the use of PA will reduce hazards in the workplace. It also will allow new work in hazardous environments such as toxic waste handling, nuclear powerplants, and undersea activities.

Psychological Effects of PA on Workers

Computerized automation in manufacturing has the potential for creating a number of psychological impacts on workers. Some of these effects may represent a temporary phenomenon resulting from a mismatch of worker skills and job requirements; i.e., experienced workers may be either over- or under-qualified for work they are doing on new automated systems.

Two of the principal effects, boredom and stress, are often closely related in that long periods of boredom at work can lead to stress in some individuals. In other ways, they represent opposite ends of a spectrum of individual reactions to work responsibilities. Boredom and stress in the automated workplace can result from the characteristics of the design of the technical system and work organization, as well as from such factors as lot size and the nature of the product manufactured.

Boredom.—PA technologies, such as NC machine tools and flexible manufacturing systems, are usually designed to run with minimal operator intervention. The human intervention that is planned into the system is of a relatively routine sort, such as making tool changes or performing other preventive maintenance duties. However, in OTA case study inter-

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[19] "Millions Paid in Robot Death," *Chicago Tribune*, Aug. 11, 1983.

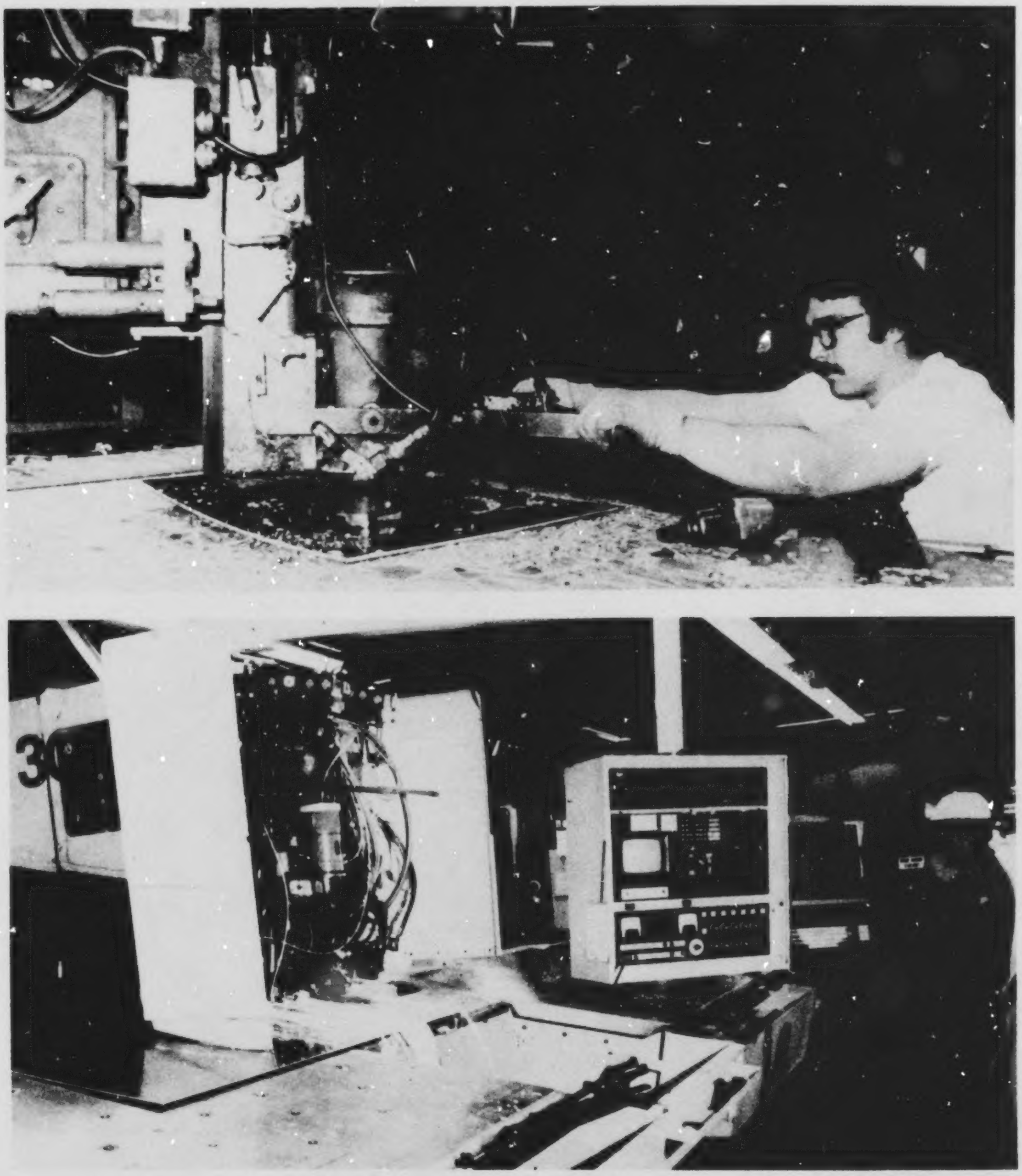

Photo credit: Lockheed-Georgia Co.

Some types of automation remove production workers from close contact with tools, and considerably reduce the physical effort required to operate them. Top photo—old method of routing flat sheet metal parts. Bottom—new method, using an NC machine views, both the owners of small shops using NC machines and the project manager of the FMS acknowledged that operator input of more than a routine nature, such as being alert to problems and acting to eliminate or minimize difficulties that may develop, was important to the smooth functioning of the production process. This need for alert and intelligent operator intervention is at odds with an important aspect of the system's design—the attempt to remove the necessity for intervention as far as possible. (However, some believe that workers will always find ways to intervene in automated processes.[20])

Some NC operators, especially those making long cuts on NC machines, reported being bored for significant portions of their working day. NC operators reported that the lethargy that developed from long periods of inaction interfered with their ability to do their work most effectively. An NC machine operator at the aircraft manufacturing company said:

> The hardest thing to do is to keep yourself on your toes checking the measurements. Just because the tape says it's good, it's not necessarily so . . . you get to relying on that tape, and what the machine can do, and sometimes the boredom—you know, you'd just as soon put another part on and just sit down again.

The boredom inherent in running a machine tool that can function automatically for periods of time is exacerbated in some cases by long running times for individual parts, so that there may be hours and sometimes even days between changeovers when a new setup is required. Parts with long running times are particularly common in the aircraft industry, so that machinists at the aircraft manufacturer and at the small shops that were subcontractors to the aircraft industry encountered many parts requiring lengthy cuts. Large lot sizes, which demand that an operator make the same part repeatedly, were also a factor in boredom.

On the FMS, boredom appeared to be less of a problem for operators; this may have been a function of the broader range of problems to which the system was subject. The larger the number and variety of unanticipated events, the less opportunity there was to be bored. As with NC machine operation, the slower periods when FMS operators appeared to be idle were actually times when they were overseeing the system and watching for problems. But it was difficult to sustain alertness during these monitoring periods. Boredom could set in because there was no immediate need for active intervention and the application of problem-solving skills. Because operators participated in the diagnosis and minor repairs of the costly and complex systems, periods of relative inactivity alternated with periods of considerable stress and pressure when problems arose with the system. This situation is similar to a number of other work environments that are highly computerized, such as nuclear powerplants.

Boredom that resulted from the way work was organized was a common complaint among NC operators who were interviewed for the case studies. Skilled NC operators who did not write part programs (i.e., the majority of those interviewed) reported that operating an NC machine was significantly less interesting and challenging than operating a conventional machine. While it is technically possible for NC machinists to do their own programing, at least for simpler parts, shop floor programing was rarely found in the sites visited for the case studies, either in the small shops or in the large NC machine shop at the aircraft manufacturing company. An experienced machinist in one of the small machine shops commented: "You get to be, in my opinion, on an NC, a little weak-minded." Another said, "They're junk as far as I'm concerned. . . . You can take a chimpanzee, the light goes on, push a button." In the sites visited, only the skilled machinists who were able to do some programing felt positive about NC machining. In the small shops, some relatively inexperienced NC operators who had been machinists for only 2 or 3 years reported fewer problems with boredom, indicating that a worker's previous experience is an important factor.

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[20] O'Toole, op. cit.

By removing programing from the shop floor, the most interesting and creative part of NC machining work has been taken out of the hands of the machinist. If the equipment operator were given the responsibility for deciding how to make the part (to the extent this is technically feasible and assuming the operator wanted the additional responsibility), boredom would be substantially reduced. A machinist in a small machine shop said:

> How could you make the job more interesting? With a machine like this [an NC lathe], get a good operator who knows what he's doing, ...give him a chance to do a setup and learn how to program the machine, so that he can look at the readout, and he can understand what the machine is doing, not just stand here and just wait and then push the button and take the part out—that would help for a while.

In some settings, however, programing or editing on the shop floor may be unavoidably constrained. In defense applications, for example, NC programs may be certified by the Department of Defense, a situation that militates against ad hoc changes by machinists.

Stress.—As in many workplaces, work-related stress is a significant feature of computer-automated workplaces. Evidence from the OTA work environment case studies suggests that for many workers stress is an important factor in the work environment, particularly for employees who have responsibility for very complex and expensive systems. Two major sources of automation-related stress were identified: 1) stress associated with working on very complicated, capital-intensive, and highly integrated systems; and 2) the lack of autonomy at work, extending in some cases to computerized monitoring by management. In many cases, stress may be considered a temporary byproduct of the change process itself; in others, it may become a permanent feature of the work environment.

In the plants studied, maintenance workers and equipment operators who had some maintenance duties reported substantial stress associated with having the responsibility for maintaining sophisticated, costly, and interdependent automated systems such as the robotic welding system at the auto plant or the materials handling system at the agricultural implements manufacturer. The combination of the complexity of the system and the pressure to minimize downtime because of the high cost of lost production added up to substantial stress for some maintenance workers assigned to systems of this sort—a problem intertwined with but also distinct from the physical hazards that such stress produces.

The most vivid example of this type of stress was in the body shop of the automaker, where welder repair supervisors reported being under extreme pressure. In the area of the body shop where the side aperture robotic welding/automotic re-spot line is located, there had been a 150 percent annual turnover rate among first-line supervisors. A general foreman said:

> This has been the hardest 3 years of my life. There isn't any relaxation . . . I've walked out of here and sat in my car, unable to move, getting myself together.

The highly integrated nature of the automated framing system, which links in series complex electronic and mechanical components, means that a failure in one part of the system spreads quickly to other areas.

The high cost of the equipment in the automated body shop is a further source of stress. Thousands of dollars worth of damage may be done if a supervisor, in haste, misdiagnoses a problem. The same problem was mentioned in regard to the FMS of the tractor producer. As one operator put it:

> When you're first down there, you're just nervous. Because everything's so expensive you don't want to break anything.

Another source of stress for workers on automated systems comes from system unpredictability. Computerized automation, as an electrician at the tractor assembly plant said, "is made to go and stop on its own program." A machinist at a small machine shop made a similar comment about working on NC machine tools:

> These NC machines—they're unpredictable. You don't know what it's going to do, the first time you run that program. You're always on edge until it's proved out.

The reduction in autonomy at work can take its toll in stress on the worker. In all of the work sites visited for the case studies, managers spoke about using PA to establish better planning and allocation of all the firm's resources. A frequently mentioned benefit in batch production was faster throughput, the ability to complete the production of a part in less time, as a result of more effective direction of the part's movement through the shop. The particular organizational choices managers made to establish greater control resulted in less autonomy for the workers involved. In general, reduction in amount of autonomy on the job is likely to be more stressful where workers previously had a greater degree of autonomy and now have either less or none at all. It also would be different in degree depending on the experience and expectations of the individual worker.

Analyzing studies of Swedish and American men, Dr. Robert A. Karasek found that work-related strain was a function not of heavy job demands alone, but of the combination of heavy job demands with restricted job control and decisionmaking latitude.[21] He concludes:

> . . . the opportunity for a worker to use his skills and to make decisions about his work activity is associated with reduced symptoms (of stress) at every level of job demands. We do not find, therefore, support for the belief that most individuals "overburdened" with decisions face the most strain in an industrialized economy. Literature lamenting the stressful burden of executive decisionmaking misses the mark. Constraints on decisionmaking, not decisionmaking per se, are the major problem, and this problem affects not only executives but workers in low status jobs with little freedom for decisionmaking . . . e.g., assembly workers, garment stitchers, freight-and-materials handlers, nurse's aides and orderlies, and telephone operators.

Machine-paced work, such as was found at the agricultural implements company and at the auto manufacturer, affects autonomy. Assembly workers at both companies were paced by the speed of the line, so that both the rate of their work and the timing of their breaks were out of their control (and also unpredictable, in the case of downtime). Lack of autonomy is not, of course, a new issue on the shop floor; it is not easily alleviated, and may indeed be aggravated, by the introduction of PA.

The increased visibility of shop operations made possible by computerized monitoring and scheduling systems allows management to spot bottlenecks more readily and take corrective action when necessary. However, what information is gathered and how it is used can result in new forms of control, both subtle and direct, over worker activities. Electronic monitoring of worker performance, and the apprehension it engenders in workers, can also add to stress in the workplace.

One system observed in the site visit to the aircraft manufacturer monitored production at 66 NC machines that are directly wired into the system. The goal is to establish direct feedback from the shop floor to management about how an important element of the NC program—the control of machine feeds—is carried out. The system and a panel that shows the status of each machine—running, running at less than 80 percent, down, or temporarily halted for part handling—is housed above the shop floor in a control room with a view of the surrounding machines. By looking at a panel, a supervisor can tell the status of all the machines in a given jurisdiction. Moreover, supervisors obtain daily reports from the system, and weekly and monthly tabulations are made in chart form for upper management.

The system seems to be widely accepted, even though some operators are apprehensive about its monitoring capabilities. (One machinist said: "It's like having a big television camera looking over my shoulder.") One of the reasons it has been accepted is that certain limits on its use by management are fairly well established after several years of operation. The company has an agreement with the union that information from the system will not be used to discipline employees, although operators said that individual supervisors could exercise various sorts of informal discipline if they so chose. Monitoring, which is not a new issue on the shop floor, was also emerging as an issue among engineers at the company because of the potential use of CAD terminals for monitoring the amount of time spent at the terminals by individual engineers. The capabilities of the technology are thus expanding the concerns about computer monitoring into higher levels of the organization, affecting personnel who lack prior experience with or coping mechanisms for it.

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[21] Robert A. Karasek, Jr., "Job Demands, Job Decision Latitude, and Mental Strain: Implications for Job Redesign," *Administrative Science Quarterly* (24), June 1979, p. 303.

Labor-Management Relations

The effects of PA on the work environment will be determined in part by management's motivations for automating and by the nature of labor-management relations.* Management might decide to introduce PA for a variety of reasons, such as: 1) to improve productivity, 2) to reduce costs, 3) to standardize production methods, 4) to enable the use of workers with fewer skills, 5) to increase control over the pace and quality of production, and 6) to get on the technological bandwagon. Who makes the decision in the organization will also have an important effect on the results. Research suggests that managers often lack the background to assess the technological options, while staff familiar with the new technologies are less able to appreciate associated strategic dimensions.[22]

Once the decision is made, the strategies employed by management for introducing PA are key in determining its impacts. Prior experience seems to be an important factor in how an organization copes with additional automation.[23] Also, the introduction of new technology may be facilitated by good intracompany communications and a "participative" management style.[24] Where the knowledge and expertise of workers is factored into the decisionmaking surrounding new technology, and information is shared, implementation problems may be minimized somewhat. In the agricultural implements case study, when asked what he would do differently, given another opportunity, the plant's manager of manufacturing replied:

> We would bring in the electrical and mechanical skilled trades people earlier so they could see the equipment installed. . . . We would have our own skilled trades people look over the shoulder of the installers. . . . We would also have brought in more systems people earlier, especially systems people with shop savvy.

Cooperative arrangements between universities and manufacturing firms may be useful devices for introducing new technologies. For example, Worcester Polytechnic Institute and the Emhart Corp. joined together to form an on-campus research center to work on practical applications problems involved in introducing robotic systems to Emhart's operating divisions.[25] Relevant personnel at all levels (production, support, and professional) participated in applications development and preparation.

The nature of labor-management relations will affect the implementation of new technology and its consequences for the work environment. Cooperation between employers, workers, and society in determining the design, implementation, and pace of change would tend to minimize potential negative effects of technological innovation.[26] Such cooperation, however, will require mutual trust among the parties involved. While such trust traditionally has not been a hallmark of labor-management relations in the United States, some observers predict that American industrial relations will become more hospitable to collaboration in the near future due to such pervasive circumstances as intense foreign competition and technological change.

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*This discussion focuses on work environment issues; it excludes wages, benefits, and other industrial relations issues. For additional discussion, see OTA Technical Memorandum "Automation and the Workplace: Selected Labor, Education, and Training Issues," March 1983.

[22] Stephen R. Rosenthal and Homayoun Vossoughi, "Factory Automation in the U.S.: Summary of Survey Responses and Initial Commentaries," School of Management, Boston University, March 1983.

[23] Donald Gerwin, "Do's and Don'ts of Computerized Manufacturing," *Harvard Business Review*, March-April 1982, p. 110.

[24] The Impact of Chip Technology, op. cit., p. 8.

[25] OTA Education and Training case study.

In response to changing worker expectations, management increasingly has been forced to pay greater attention to the needs of its work force, beyond the traditional ones of fair wages and benefits. This trend has been growing since the 1960's and 1970's, and is not limited to either new technology or PA. In addition to such provisions as profit-sharing and job security, workers have been demanding a greater say in matters that directly affect their workplace; where management has begun to tap into this knowledge and experience they have often discovered a new source of support and insights.

The attention being given in the United States to the Japanese style of labor-management relations seems to be affecting the nature of labor-management relations in this country. In particular, cooperative labor-management efforts in solving workplace problems have been gaining popularity in the United States. These innovative work experiments are known by a variety of names, including Quality of Working Life Programs, Quality Circles, Labor/Management Committees, and Employee Involvement Programs. A recent Department of Labor document identifies and describes over 200 cooperative labor-management programs;[27] the International Association of Quality Circles promotes quality circles through conferences, training activities, and educational materials; and consulting firms are beginning to provide guidance for setting up such efforts. Membership in participative programs is usually voluntary, and training in problem-solving techniques is provided. Generally, their purpose is to identify and help to solve everyday problems on the job. Such programs have had mixed results, reflecting the diversity of approaches taken, management styles, and work force heterogeneity. This makes it difficult to generalize about the goals of these programs or to evaluate their effectiveness.

Cooperative efforts can occur in either union or nonunion settings. Indeed, their presence in nonunion settings is attributed by some as a factor constraining further unionization. In plants that are unionized, cooperative groups usually deal with workplace issues that fall outside the collective bargaining framework. Quality circles, modeled after the quality control circles in Japan, are usually management-initiated to improve product quality and productivity. For this reason, some unions view them as management devices to increase productivity at the expense of workers, and sometimes as a way to fight unions, rather than as efforts to increase worker participation. The fragility of some quality of work life (QWL) programs has been demonstrated recently when UAW union locals in GM plants in both Michigan and California called for either disbandment or reevaluation of QWL programs, criticizing management for abusing the cooperative spirit of the programs.

In the case of the introduction of new technology, successful labor-management cooperative efforts should have a positive effect on the way in which it is perceived in the workplace. For instance, the UAW-Ford Employe Involvement Program is viewed by employees as having a beneficial effect on their jobs and the work environment.[28] Where such programs are functioning well, they could help to ease the changes brought about by the introduction of PA. The principal uncertainty surrounding such programs appears to be, however, their relationship to the perhaps more fundamental issue of job security. Labor-management cooperation appears to be sounder where the fact of jobs is not in question.

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[26] Donald Kennedy, Charles Craypo, and Mary Lehman (eds.), *Labor and Technology: Union Response to Changing Environments* (Department of Labor Studies, The Pennsylvania State University, 1982).

[27] "Resource Guide to Labor-Management Cooperation," U.S. Department of Labor, Labor-Management Services Administration, October 1983.

[28] "UAW-Ford Employe Involvement: A Special Survey Report," Center Report 1, UAW-Ford National Development and Training Center, 1982.

If PA is perceived to be a growing threat to job security, that perception may interfere with other labor-management cooperative programs. Other factors that may hinder new joint programs are the reluctance of parties to fundamentally revise their attitudes, external events such as a recession, and lack of commitment by one or the other party.[29] Some experts believe that shifts in labor-management relations in recent times have been the result of recession and do not represent any fundamental change in the attitudes of either management or labor.[30] The tenor of negotiations in major collective bargaining to take place in 1984 and beyond will bear watching to see if there are perceptible trends in a changing climate of labor-management relations.

The latest Bureau of Labor Statistics data (September 1981) give the number of employed wage and salary workers in labor organizations as 23 percent and the percentage represented by labor organizations as 25.7 percent, although the proportion varies among industries (see table 51).[31] Experts suggest that these percentages are currently a few points lower. The approaches to new technology and accompanying levels of concern have varied among unions, although overall concern is growing. While the views of unionized workers concerning new technology are known, less is known about the attitudes of workers in nonunionized companies. However, they would likely cover a broad range depending on the size of the company and the type of labor policies employed. One study found that some of the large nonunion companies resembled the large unionized companies in their labor practices, and some even had policies that were more restrictive than those of union contractual arrangements.[32] In the small nonunion shops visited for OTA work environment case studies, workers interviewed seemed to accept the fact that the future lies in increasing automation, whether or not they like it personally.

Unions have attempted to minimize what are perceived as the socially harmful effects of new technologies on the labor force, such as job displacement and deskilling. Such efforts include collective bargaining, organizing, and political strategies.[33] For instance, technology clauses are becoming more common in collective bargaining agreements, and some unions provide model contract language to their local bodies that covers the introduction of new technology. Adjustment procedures and programs, such as advance notice and provisions for training related to new technology, increasingly are included in union contracts. Recently AT&T and the local operating companies that were spun off in January 1984 agreed to offer retraining for other company jobs at company expense, and thus job security, to any worker whose job will be eliminated by the introduction of new technology.

The International Association of Machinists and Aerospace Workers' Technology Bill of Rights, which outlines a specific list of worker rights with respect to the introduction of new technologies, has been provided to local unions as a guide to be used during contract negotiations (see table 52). However, in a recent contract negotiation in California the company ignored the union request for one of the items listed on the Bill of Rights—the retraining of workers whose jobs are eliminated because of new technology.[34]

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[29] Irving H. Siegel and Edgar Weinberg, *Labor-Management Cooperation: The American Experience* (Kalamazoo: W. E. Upjohn Institute for Employment Research, 1982).

[30] Sar A. Levitan and Clifford M. Johnson, "Labor and Management: The Illusion of Cooperation," *Harvard Business Review*, September-October 1983, p. 8.

[31] "Earnings and Other Characteristics of Organized Workers," U.S. Department of Labor, Bureau of Labor Statistics, September 1981.

[32] Jack Stieber, Robert B. McKersie, and D. Quinn Mills (eds.), *U.S. Industrial Relations 1950-1980: A Critical Assessment* (Madison, Wis.: Industrial Relations Research Association, 1981), from chapter entitled "Large Nonunionized Employers" by Fred K. Foulkes.

[33] Kennedy, Craypo, and Lehman, op. cit.

[34] "Machinists Clear Pact With McDonnell, Bolstering Firm's Tough Stand on Costs," *Wall Street Journal*, Nov. 8, 1983.

Table 51.—Employed Wage and Salary Workers Represented by Labor Organizations[a] by Occupation and Industry, May 1980

(numbers in thousands)

Occupation of current job	Total	Agriculture	Mining	Construction	Manufacturing	Transportation and public utilities	Wholesale trade	Retail trade	Finance and services	Forestry and fisheries	Public administration
	Percent of employed wage and salary workers										
All occupations[b]	25.7	3.8	35.2	33.1	34.8	51.5	12.6	10.5	19.7	16.1	40.5
White-collar occupations	18.5	2.7	10.2	12.2	12.3	38.4	4.6	8.5	20.5	(c)	36.3
Professional, technical, and kindred workers	27.7	(c)	6.5	19.4	11.3	33.8	4.1	6.4	32.4	(c)	31.3
Managers and administrators, except farm	9.7	(c)	(c)	12.7	5.9	16.9	3.9	6.1	10.1	(c)	26.2
Clerical and kindred workers	19.2	(c)	16.7	8.2	18.2	49.2	7.8	13.9	11.2	(c)	42.6
Sales workers	5.0	(c)	(c)	(c)	5.4	(c)	2.2	5.4	4.4	—	(c)
Blue-collar workers	41.4	8.1	47.1	39.6	46.9	62.6	28.9	21.3	20.8	(c)	41.0
Craft and kindred workers	41.2	(c)	51.0	41.1	45.8	67.7	21.8	12.9	23.2	(c)	45.0
Carpenters	33.9	(c)	(c)	31.3	42.7	(c)	(c)	(c)	(c)	(c)	(c)
Construction craftworkers, except carpenters	50.4	(c)	(c)	46.4	67.6	70.3	(c)	(c)	40.7	(c)	(c)
Mechanics and repairers	42.9	(c)	(c)	39.3	57.1	66.0	16.8	10.8	21.1	(c)	46.2
Operatives and kindred workers	43.5	(c)	42.7	39.6	46.9	57.0	36.1	22.6	22.3	—	41.4
Operatives, except transport	42.4	(c)	41.1	39.9	46.1	60.9	33.7	22.4	20.0	—	(c)
Drivers and delivery workers	43.0	(c)	(c)	39.9	45.6	53.2	37.4	21.7	26.6	—	(c)
Other transport equipment operatives	68.2	—	(c)	(c)	69.8	88.3	(c)	(c)	(c)	—	(c)
Nonfarm laborers	35.1	7.5	(c)	34.4	52.2	64.8	24.1	28.9	13.2	(c)	32.5
Construction	34.4	—	—	34.4	—	—	—	—	—	—	—
Manufacturing	52.2	—	—	—	52.2	—	—	—	—	—	—
All other nonfarm laborers	29.7	7.5	(c)	—	—	64.8	24.1	28.9	13.2	(c)	32.5
Service workers, including private household	18.4	(c)	(c)	(c)	36.5	60.1	(c)	5.8	17.0	(c)	55.0

[a] Includes members and nonmembers in bargaining units.

[b] Includes farm workers not shown separately.

[c] Base less than 75,000.

NOTE: Due to rounding, sums of individual items may not equal totals. Dashes (—) indicate no workers in cell.

SOURCE: Bureau of Labor Statistics, "Earnings and Other Characteristics of Organized Workers, May 1980," Bulletin 2105, September 1981, p. 27.

Table 52.—Workers' Technology Bill of Rights

I. New Technology shall be used in a way that creates jobs and promotes community-wide and national full employment.

II. Unit Labor Cost savings and labor productivity gains resulting from the use of New Technology shall be shared with workers at the local enterprise level and shall not be permitted to accrue excessively or exclusively for the gain of capital, management, and shareholders.

III. Local communities, the states and the nation have a right to require employers to pay a replacement tax, on all machinery, equipment, robots, and production systems that displace workers, cause unemployment and, thereby decrease local, state, and federal revenues.

IV. New Technology shall improve the conditions of work and shall enhance and expand the opportunities for knowledge, skills, and compensation of workers. Displaced workers shall be entitled to training, retraining and subsequent job placement or re-employment.

V. New Technology shall be used to develop and strengthen the U.S. industrial base, consistent with the Full Employment goal and national security requirements, before it is licensed or otherwise exported abroad.

VI. New Technology shall be evaluated in terms of worker safety and health and shall not be destructive of the workplace environment, nor shall it be used at the expense of the community's natural environment.

VII. Workers, through their trade unions and bargaining units, shall have an absolute right to participate in all phases of management deliberations and decisions that lead or could lead to the introduction of new technology or the changing of the workplace system design, work processes and procedures for doing work, including the shutdown or transfer of work, capital, plant and equipment.

VIII. Workers shall have the right to monitor control room centers and control stations and the new technology shall not be used to monitor, measure or otherwise control the work practices and work standards of individual workers, at the point of work.

IX. Storage of an individual worker's personal data and information file by the employer shall be tightly controlled and the collection and/or release and dissemination of information with respect to race, religious or political activities and beliefs, records of physical and mental health disorders and treatments, records of arrests and felony charges or convictions, information concerning sexual preferences and conduct, information concerning internal and private family matters, and information regarding an individual's financial condition or credit worthiness shall not be permitted, except in rare circumstances related to health, and then only after consultation with a family or union-appointed physician, psychiatrist or member of the clergy. The right of an individual worker to inspect his or her personal data file shall at all times be absolute and open.

X. When New Technology is employed in the production of military goods and services, workers, through their trade union and bargaining agent, shall have a right to bargain with management over the establishment of Alternative Production Committees, which shall design ways to adopt that technology to socially-useful production and products in the civilian sector of the economy.

SOURCE: International Association of Machinists and Aerospace Workers.

One of the most controversial subjects of labor-management relations involving the introduction of new technology will be work rules. Work rules are central to the collective bargaining system in the United States, and are viewed by some as one of its great strengths.[35] This system of job control is also closely related to the tenets of Taylorism that break down work into sets of discrete tasks.[36] In work sites that are becoming more and more automated, management is likely to demand increasing flexibility in deploying workers. As noted in chapter 4, successful implementation of PA may involve substantial changes in production processes and in the nature of work to be done by people as opposed to machines. These changes will raise questions concerning job definition—about which tasks are combined to make which jobs. Work rules assure that certain jobs contain certain tasks, but PA may make such jobs obsolete. Job definition changes may be reflected in collective bargaining requests from management for relaxing and changing work rules, in return for union demands for worker benefits such as job security or profit-sharing. In this respect, nonunion shops may be able to respond more quickly to the changing workplace demands of new technology.

Any discussion of restructuring work in automated environments in ways that would enhance the workplace needs to be framed in the context of how the work rule issue evolves. Management's ability to take innovative approaches to implementing PA may be constrained by work rules that are outmoded and difficult to change. In return for increased flexibility in deploying workers, management may need to be more responsive in such matters as increased labor involvement in decisions concerning the implementation of new technology or job security.

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[35] Robert M. Kaus, "The Trouble With Unions," *Harper's*, June 1983, p. 29.

[36] Michael J. Piore, "American Labor and the Industrial Crisis," *Challenge*, March-April 1982, p. 9.

European and Japanese Experiences

In Western Europe and Japan, mechanisms for dealing with workplace concerns have generally been applied to the introduction of new technology, and in many cases the laws specify how such introduction is to be handled. For example, the laws of West Germany, Norway, and Sweden provide for worker involvement in technology issues, and labor is routinely represented on corporate boards. It is important, however, to point out that the culture and traditions of Europe and Japan regarding attitudes and practices in the workplace differ from the those of the United States, especially in the area of labor-management relations. In general, the labor-management relations of these countries are characterized by a more cooperative atmosphere and greater worker participation than has been the case in the United States.

Japan

There seems to be a broad consensus among labor, management, scholars, and the government in Japan that new technologies should be applied in ways that will humanize life and the quality of work.[37] For example, in 1983, a joint effort of government, industry, and academia began to develop robots to perform jobs too hazardous or unhealthy for human beings (known as "extreme-job" robots).[38]

Much has been written about Japanese management style and its effect on the work environment. In particular, the nature of labor-management relations provides many opportunities for information exchange and sharing, both between management and labor and among workers themselves.[39] Such information-sharing is key in Japanese companies, and provides the basis for quality circles at firm, plant, and workshop levels. It is also effective in the introduction and use of new technologies such as PA.

There are two principal types of worker participation in Japan that exist primarily in the private sector: 1) direct shop floor participation, such as small group participative activities like quality control circles; and 2) indirect representational forms, such as labor-management consultation systems.[40] Small production study groups have played a vital role in developing employee participation in problem-solving. Unions and quality control circles have often been involved in designing robot applications within the plants. Those companies with the most active quality control circles have also been the leaders in the use of robots.[41]

Participatory work structures represent one of a number of actions designed to deal with the effects of labor shortages in Japan.[42] They were usually introduced as part of a corporate strategy to make firms more attractive to highly educated potential recruits and to reduce the likelihood of turnover and labor unrest. Thus, worker participation originally was more an obligation of each employee than an opportunity to actively participate in solving workplace problems.

Quality control circles often provide a good opportunity to promote "humanization of work" in the workplace.[43] Workers are taught fairly simple statistical quality control techniques and modes of problem-solving. They are guided by leaders, often foremen, in the selection and solving of job-related quality problems.

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[37] Kazutoshi Koshiro, "The Employment Effect of Microelectronic Technology," *Highlights in Japanese Industrial Relations*, The Japanese Institute of Labor 1983, p. 87.

[38] "Gov't-Industry Project Will Start On 'Extreme-Job' Robots," *The Japanese Economic Journal*, Mar. 8, 1983, p. 10.

[39] Haruo Shimada, "Japanese Postwar Industrial Growth and Labor-Management Relations," paper presented at the 35th Annual Meeting of American Industrial Relations Association, December 1982, p. 7.

[40] Robert E. Cole, "Participation and Control in Japanese Industry," prepared for Conference on Productivity, Ownership and Participation, Agency for International Development, U.S. Department of Labor, May 1983.

[41] Paul H. Aron, "Robotics in Japan: Past, Present, Future," a presentation to Robots VI Conference, March 1982, p. 4.

[42] Cole, op. cit.

[43] Takeshi Inagami, "QC Circle Activities and the Suggestion System," *Highlights in Japanese Industrial Relations*, The Japanese Institute of Labour, 1983, p. 67.

The second type of worker participation is the labor-management consultation system, a representational form of participation by union officials on behalf of employees in which employers and employees discuss management policies and plans.[44] The focus is on improving communications between management and labor, improving working conditions, and stabilizing labor relations. Joint consultation provides a framework in which negotiations on working conditions can be conducted on a continuous basis rather than as a focus of collective bargaining. Participants do not view them as providing the primary basis for increased worker participation in management.

While popular accounts of Japanese labor-management relations highlight labor's input, on closer inspection it can be seen that managerial control is strong. Matters relating to the operation of the firm, production, and personnel are most often settled by company notification or explanation.[45] Management retains its prerogative to act unilaterally but, where possible, uses the joint consultation system to solicit worker and union opinion. Management carefully controls and guides the activities of small group participatory activities, and would resist more direct threats to its prerogatives that might be tried through legislative means.[46] This system is facilitated by a relatively high level of homogeneity in the Japanese population and labor force.

The Japanese system offers several advantages relative to the introduction of new technology. Generally, where new technology is introduced workers are reassigned rather than laid off. However, there are signs that this Japanese practice, which in the past has been an understanding and not contractual in nature, may be changing (see ch. 4). Recently there has been evidence that Japanese workers are becoming more concerned about the impact of new technology on employment. Unions have begun to win agreements aimed at protecting workers against the potential negative effects of automation.

For example, Nissan Motor Co. and auto workers have negotiated what is likely to become a model technology agreement for other unions. It requires "consultation" between labor and management before the introduction of labor-saving automation and prohibits the company from dismissing or laying off workers because of new technology. Nissan promises not to downgrade positions or reduce wages and working conditions, and agrees to provide union members with necessary education and training to facilitate adjustment, in accordance with their aptitude and ability. The fact that this is a written agreement rather than a tacit understanding makes this contract important and unique in Japan.

While quality control circles are widely used in Japan, it is interesting to note that the Japanese companies operating in the United States have been much more cautious about instituting such mechanisms because of differences in the work environment and a much more heterogeneous work force. Where such practices are instituted, they are usually introduced very gradually to allow time for workers to adjust to the information-sharing and to learn the problem-solving techniques of quality circles. The Nissan truck plant in Smyrna, Tenn., which opened in 1983, will be watched carefully as an experiment in Japanese management applied to an American work force. Early reports give it high marks, but some observers suggest that it is too early to evaluate how well it will work over time.

Norway and Sweden

There are several Scandinavian attempts to ensure worker involvement in anticipating and controlling the effects of new technologies on the workplace.

In both Norway and Sweden, workplace legislation is in effect and workers are represented on corporate boards.

In Norway, the unions, employers, and the state have tried to shape the actual direction of technological change.[47] The 1977 Working Environment Act gave workers the right of advance notice of all proposed technological changes, access to company data banks, and participation in all decisions that affect the form and content of their jobs.[48]

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[44] Cole, op. cit.
[45] Ibid.
[46] Ibid.

Legislation has specified conditions to the extent of mandating efforts to avoid undiversified, repetitive work and work that is governed by machine or conveyor belt in such a manner that the employees themselves are prevented from varying the speed of the work. Otherwise "efforts shall be made to arrange the work so as to provide possibilities for variation and for contact with others, for connection between individual job assignments, and for employees to keep themselves informed about production requirements and results."[49]

Technology agreements negotiated by labor and management also affect the ability of workers to influence the direction of workplace technological change.[50] They establish a variety of rights for workers in the areas of information, training, participation, and bargaining concerning technology-related matters in the workplace. Workers are guaranteed both job-related training and general education about technical systems and their design.

In Sweden, two laws protect employees in relation to workplace changes. The first is the Act on Employee Participation in Decisionmaking (1977), which obliges the employer to inform and negotiate with the union before making decisions on any major operational changes, including implementation of new technology.[51] The second law, the Swedish Work Environment Act of 1978, sets out general demands that can be made with regard to working conditions. It includes basic rules on both the physical and the psychological work environment. An essential point is that employees are to have an opportunity to influence the design of the work environment. The focus is on the working premises, equipment, techniques, and working methods. Both laws are supplemented by collective agreements between employers and employees.

In addition to work environment laws, indications are that the Swedish Government is committed to research in how changing technologies affect workers.[52] The pivotal research institution in the work environment field in Sweden is the research department of the National Board of Occupational Safety and Health. A large proportion of total funds allocated for work environment research in Sweden is awarded by The Swedish Work Environment Fund. Founded in 1972 and financed by means of a payroll tax levied on all employers, the Fund supports research and development, training, and information to improve the work environment in a broad sense, including co-determination (requirement that employers negotiate with unions on any plans for major changes in company activities), psychosocial work environment problems, and work organization.[53]

The Swedish Centre for Working Life is an independent research institute supported by the Fund and the government. It focuses on research problems concerned with individuals and groups in working life, industrial relations, co-determination, the organization of work, and its mode of operation.

A recent summary of considerations and proposals put forth by the Swedish Commission on the Effects of Computerization on Employment and Working Environment, published in April 1981, states:

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[47] Leslie Schneider, "Technology Bargaining in Norway," prepared for the Ministry of Local Government and Labor, Oslo, Norway, March 1983.

[48] Robert Howard, "Brave New Workplace," *Working Papers for a New Society*, vol. 7, November-December 1980, p. 28.

[49] Act of 4 February 1977 relating to Worker Protection and Working Environment, as subsequently amended last by Act of 13 June 1980, Directorate of Labour Inspection, Oslo, Norway, November 1980.

[50] Schneider, op. cit.

[51] Kerstin Norrby and Barbara Klockare, The Swedish Agency for Administrative Development, "Decision-making, Assessment of Effects and Participation Regarding Computerization in the Swedish Governmental Administration," a paper to the Conference on System Design, IFIP Working Group, September 1982.

[52] Dennis Chamot and Michael D. Dymmel, "Cooperation or Conflict: European Experiences With Technological Change at the Workplace" a publication of the Department for Professional Employees, AFL-CIO, Washington, D.C., 1981.

[53] "Programme of Activities and Budget 1981-82-1983-84," Swedish Work Environment Fund, 1982.

> It goes without saying that the Commission holds the view that all possibilities to influence how computer technology is used should be fully exploited.[54]

This includes the use of industrial robots to eliminate heavy, monotonous, restrained jobs and jobs that are hazardous to health. The Commission also concluded that an increase in the use of computer technology in manufacturing processes increases isolation at work. It endorsed new technology if its use includes both an effort to create a better working environment and co-determination exercised by employees.

West Germany

In West Germany, research in the areas of humanization of work and co-determination are considered to be closely related.[55] The government has funded work humanization projects since 1974, including safety and health and work reorganization. Germany's co-determination law requires that workers be represented by an elected works council that works with management on productivity and other issues. However, the extent to which ordinary employees have input to the works councils is questionable.[56] German managers are legally obligated to negotiate all major decisions at the plant level with the work councils and submit the outcome to the supervisory boards (equivalent to American boards of directors). According to a recent analysis, "Their [German] commitment to technological expertise, enduring customer relationships, long-term results, and the achievement of consensus leads most successful German companies to work closely with their employees in integrating new technology with the capabilities of the work force."[57]

During the 1960's, the social implications of increasing automation and rationalization measures fueled the debate over the reform of working conditions. In addition to the prevention of accidents and occupational diseases, the improvement of working conditions began to include, for example, ergonomic workplace and machine design, as well as new forms of organization of work permitting greater individual responsibility and more opportunities for acquiring qualifications.

These activities gave rise to the Humanization of Working Life Program in 1974 in the Federal Ministry of Research and Technology and the Federal Ministry for Labor and Social Affairs. The general objective of this research program is to investigate the possibilities for better adapting working conditions to human needs. It combines the goal of establishing improved health protection on the job with that of achieving better opportunities for employees to gain qualifications and develop their abilities. The program includes projects to redesign workplaces where monotony is often combined with time pressure, social isolation, and a low skill requirement.

The program, which is supported at least in principle by all the parties represented in the German Bundestag and by both employer organizations and trade unions, has as its aims:

- to formulate safety data, standards, and minimum requirements for machinery, installations, and workplaces;
- to develop work technologies adapted to the worker;
- to elaborate models for work organization and workplace design; and
- to disseminate and apply scientific findings and industrial experience.

The humanization program has led to increased sensitivity to problems regarding working conditions and work rationalization in industry and administration, and to an interdisciplinary science in the field of labor. It has given rise to projects to improve health protection on the job, in particular projects looking at stress problems and the development of technologies for the reduction of heavy, dangerous, or monotonous work. The program also fosters experiments with new forms of work organization, aimed at new technical and organizational production systems.

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[54] From a summary of considerations and proposals put forward by the Swedish Commission on the Effects of Computerization on Employment and Working Environment in its report "Computerization in Industry—Effects on Employment and Working Environment," April 1981.

[55] Chamot and Dymmel, op. cit.

[56] "Moving Beyond the Assembly Lines," *Business Week*, July 27, 1981, p. 87.

[57] Joseph A. Limprecht and Robert H. Hayes, "Germany's World-Class Manufacturers," *Harvard Business Review*, November-December 1982, p. 142.

The results of humanization research have already been incorporated into national legislation in several cases—e.g., into the 1975 Workplaces Regulation Act and the guidelines governing it. Since mid-1980, the Federal Center for the Humanization of Work has been affiliated with the Federal Center for Occupational Safety and Accident Research as an independent organizational unit. It is responsible for incorporating the results of government-promoted research concerning the humanization of work into everyday working conditions.

One of the workplace areas to be studied is the introduction of robots, with a view to avoiding the creation of jobs that are uninteresting and monotonous for humans and that may entail considerable strain and stress. Continued support is to be given to improved forms of work organization as well as to solution of technical and organizational problems in general.[58]

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[58] Alfred Hassencamp and Hans-Jurgen Bieneck, "Technical and Organizational Changes and Design of Working Conditions," a summary of the experiences and results of the West German research program "Humanization of Work," 1982.

Appendix 5A.—Methodology Employed in OTA Case Studies of the Effects of Programmable Automation on the Work Environment

Case 1
Small Metalworking Shops

This case study is based on visits to seven metalworking shops in Connecticut. They were chosen from a group of sites suggested by the Numerical Control Society, a trade magazine, and two interviewees at the job shops themselves. They span a range of shop sizes. Shops were not chosen for study because of their "representativeness"; indeed, the chief selection criterion was that the establishment be particularly advanced, for its size, in the number of NC machines in use. Every shop contacted agreed to participate in the study. The final group of 7 was drawn from a pool of 11 shops that agreed to participate.

Visits lasted from a half day to a full day. At each site, the researchers began by speaking to the president or vice president, generally for an hour or more. Subsequent interviews were held with programers, foremen, working foremen, and shopfloor workers. For the most part, the people interviewed were selected by a manager or foreman based on the research team's preferences for talking to a cross section of the shop's work force. In cases where the researchers asked to speak to a specific person, these requests were honored. At some shops, the interviewers were invited to select any of the employees for interviews.

Interviews were open-ended, based on a prepared interview guide. Generally, they lasted from one-half to 1 hour, with the longest running over 2 hours. Nearly all of the interviews were tape-recorded, with the consent of the interviewees, and most of the quotations used in the report are based on transcripts of the taped interviews. Interviews were held in an office or room in the plant. In some cases, they were conducted in the president's or vice president's office. With very few exceptions, the interviewers were alone with the interviewee. All interviews except one focused on one person only; at one plant, the president and vice president were interviewed together.

Altogether, four presidents, four vice presidents, five programers. five foremen and working leaders, one quality control supervisor, one full-time machine repairer, and fifteen machinists and operators were interviewed.

Agricultural Equipment Company

This case study is based on data gathered during a 6-day trip to the city in which the components plant and the nearby tractor assembly facility are located. Three days were spent touring the company's manufacturing facilities and conducting interviews with members of management. The balance of the visit was spent interviewing members of the local union.

The company was extremely cooperative, providing the research team with an excellent overview of plant operations and affording them freedom to explore areas of particular interest in greater depth. The first 2 days were spent gaining a broad introduction to the components plant and the tractor assembly facility, and the third day was spent in followup investigation and interviews, particularly at the site of the flexible manufacturing system (FMS). Interviews were conducted with company personnel ranging from the vice president for manufacturing to first-line supervisors in the tractor assembly plant. Also interviewed were the plant manager; the managers of manufacturing engineering, mechanical services, and process and tooling; several supervisory personnel; and the project manager and systems manager for the FMS—all at the components plant. Interviews were also conducted with the plant manager, manager of manufacturing engineering, and the controller at the tractor assembly plant.

Interviews were open-ended, based on a prepared interview guide but tailored to the individual being interviewed, and lasted from 15 minutes to several hours. Tours and interviews were supplemented by several brief presentations by company personnel focusing on different aspects of automation at the company, by written materials supplied by the company, and by relevant articles and information obtained by the researchers from other sources.

The worker interviews on which this study is based were arranged by the union, the United Automobile Workers, and carried out in the local union hall. The local union was very cooperative about arranging interviews and providing the space in which to conduct them. A semistructured open format, similar to that used at the company but designed specifically for interviewing workers, was used to interview people both individually and in groups. The union was asked to arrange interviews with workers from the FMS area and from those utilizing the company's labor reporting system. Also requested were interviews with workers from the components plant and the tractor works, in skilled trades as well as production, of varying ages and seniority. A total of 18 workers were interviewed through the union. In this situation selection bias was unavoidable, but the workers interviewed appeared to represent a range of viewpoints with respect to computerized technology.

Even the workers who were most critical of the way in which the company was implementing new programmable technologies expressed a basic respect for the company and its management.

Commercial Aircraft Company

The fieldwork for this case was conducted during an 8-day visit to the west coast in April 1983. Before the arrival of the research team, contact was made with the company and with the two major unions at the research sites, the International Association of Machinists and a professional engineers' association. Both the company and the unions were very cooperative, allowing access and arranging interviews which form the basis of the analysis.

At the company, a series of interviews had already been scheduled when the researchers arrived. Interviewees were selected by the company management based on the researchers' request for interviews with a wide range of managerial personnel, from higher level management involved in the implementation and management of computerized technology to first-line supervisors in production departments where programmable automation was in use. These interviews were supplemented with additional interviews arranged at the request of the research team during the 5-day visit to the company. All interviews with members of management were conducted at or near the worksite of the particular manager or supervisor, with a member of management, who acted as host to the research team, present at the interview.

Interviews were open-ended, and their structure was based on an interview guide prepared before the start of the visit. The actual content of each was tailored to the particular individual being interviewed, based on his role in the company. The length varied from one half hour to several hours in length. In some cases, a tape recorder was used, and all lengthy quotations are transcribed from the tapes. A few of the interviews were preceded or followed by prepared presentations which outlined the features of a particular computerized system or technology-related issue at the company. Followup interviews, where necessary, were conducted by telephone, and additional written material was obtained from the company. Company sources were also supplemented with written material available elsewhere.

Interviews with union members were conducted through the auspices of the two unions. Interviewees were chosen by the unions, based on general guidelines set by the research team. The researchers asked to interview members of the bargaining unit who were affected by new technology, particularly engineers affected by the use of computer-aided design, and machinists and other workers (e.g., inspectors, programers, and layout workers) affected by computerized technology, especially NC. Because of the way in which interviewees were selected, the workers interviewed cannot be viewed as being a randomly selected sample of all workers at the company. While some attempt was made to ensure that a range of views was represented, the intention of the researchers was to capture a sense of the variety of reactions to programmable automation in a few selected work areas, rather than to attempt in a very brief visit to assemble a "representative" group.

Interviews with union members were conducted at or near the union hall, and were, like the interviews with managers, open-ended. Again, an interview guide was used, and the specific questions adapted to the particular employees interviewed. Most interviews were group interviews, and all were tape-recorded. Generally, interviews with union members lasted from 1 to 2 hours, depending on the size of the group.

In total, interviews were conducted with 14 members of management, 4 first-line supervisors, 6 engineers and technicians, and 38 shop floor employees, as well as with officers of both local unions, including the presidents.

The Auto Company

The 3-day visit to the auto plant took place in May 1983, and included an introductory discussion and tour of the plant conducted by the Personnel Department and a brief interview with the plant's manufacturing engineering manager on the third day. The research team spent the remainder of the 3 days interviewing workers, shop floor managers, union stewards, and union committeemen who work in the automated welding facility—the "body shop."

Throughout the visit, both management and the union cooperated completely with the research team. The plant management permitted unrestricted access to the body shop. The superintendents in the body shop, in turn, allowed unrestricted access to supervisors and workers. This access included the freedom to move independently around the shop floor and to speak with workers on break at their workstations. Only through this unique cooperation was the research team able to gain, in a brief time period, a detailed knowledge of how automation affected individual jobs and how the workers on these jobs perceived the affects of the system.

During the 3 days, the research team interviewed:

- the welder repair and production superintendent;
- two welder repair general foremen and one welder repair foreman;
- one production general foreman and one production foreman;
- three welder repairmen;
- 19 production workers (6 first-shift workers were interviewed for more than an hour at the union hall and an additional 15 to 45 minutes on the job; the remainder were interviewed either in the union hall or in the plant);
- the production and skilled trades' union stewards on first shift, and the production and skilled trades committeemen; and
- a number of other managers, union officials, and workers with knowledge of some aspects of automation and the body shop.

The group above represented about 30 percent of the production workers, 15 percent of the skilled tradesmen, 70 percent of the supervisors, and all of the union officials with first-shift responsibilities in the part of the body shop containing robots.

Interviews with supervisors, union officials, and workers were open-ended and loosely structured, based on a prepared interview guide. The interviews at the union hall were taped, with the consent of the interviewees. The quotations used in the report are from the taped interviews or from notes taken during the meetings by someone other than the principal interviewer. The research team conducted followup interviews of 15 to 45 minutes with certain individuals on the second and third day. Additional followup interviews were conducted with union officials and body shop supervisors over the telephone. An interview of the corporation's director of manufacturing was also conducted over the telephone.

Chapter 6

Education, Training, and Retraining Issues

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Chapter 6

Education, Training, and Retraining Issues

Summary of Major Findings

Programmable automation (PA) is one of a number of forces currently reshaping the roles for and values assigned to education, training, retraining, and related services such as career guidance and job counseling.

Strong basic skills in math, science, and reading serve as the foundation for instruction for programmable automation. Instruction for semiskilled and skilled production line workers in automated facilities must emphasize conceptual and problem-solving skills as much as motor skills. Instruction for technician-level occupations common to automated facilities must focus on the development of multiple skills (broader training) and on an understanding of how programmable equipment interfaces with other components of the manufacturing process. Instruction for engineers who work in automated plants must emphasize a broader based knowledge of engineering operations and stronger management skills.

A key ingredient in successful PA instructional programs is **close cooperation between industry, educators, labor, and government** in such areas as skills assessment, curriculum design, equipment acquisition, location of qualified instructors, and job placement. However, in most cases, this degree of intersector cooperation is left to chance and often does not occur.

The present capacities of the U.S. instructional system, characterized by inadequate facilities, shortages of equipment, and an inadequate supply of instructors, may constrain the establishment of adequate skills-development strategies for programmable automation. This is as true for most industry-based instructional programs as it is for programs offered by more traditional public and private educational institutions. There are no indications that these barriers to instruction will disappear over time, without specific, corrective actions.

Population groups served by different types of instructional programs, as well as the numbers of individuals taking advantage of instructional services, are changing. However, individuals who are most likely to be affected by technological and economic change—those with lower incomes and lower levels of educational attainment—seem to be the least inclined to enroll in instructional programs in order to develop new, more marketable skills.

Special approaches will be required to ensure that retraining programs and job counseling/outplacement assistance geared to the unique needs of displaced workers are developed and implemented. In the past, retraining for displaced workers has often been a "force fit," and participation rates have been low.

Introduction

The use of programmable automation in manufacturing is one of a number of forces reshaping education, training, retraining, and educational guidance/job-counseling services in the United States. Among the other forces creating increased demand for instruction are: 1) technological change occurring in office and service sector environments, 2) broad-based economic change induced by U.S. participation in international markets and shifts in demand for goods and services, 3) demographic change, and 4) increased interest in education and training for personal and professional development. These forces may, in the long run, facilitate or impede the establishment of well-founded instruction for programmable automation, depending on the aggregate demand they generate for skills development and the instructional resources required to address this demand.

Accordingly, the goals of this chapter are threefold: to describe how the roles for and values assigned to instruction are changing as a result of economic, technological, and demographic change and the heightened sense of the "unknown" created by this change; to examine specific instructional responses to skills requirements for programmable automation at this early stage of adoption of the technologies; and to discuss how present capacities of the U.S. instructional system may affect skills development strategies for programmable automation in the long term.

A wide variety of sources, including education and training literature, personal interviews, and site visits to manufacturing facilities and instructional centers, were used in developing this account of a changing national instructional system and in depicting how programmable automation is being addressed by that system. Fourteen in-depth case studies created for OTA describe selected, currently available education, training, and retraining geared to PA. They served as a particularly rich source of information in the development of this section of the report.

The Changing Context for Education, Training, and Retraining

In 1983, a number of studies were released which reflected growing national awareness of the importance of education, training, and retraining to international economic competitiveness, as well as concern over the current state of elementary, secondary, and postsecondary instruction in the United States. Among the studies that have received the most attention are those of the National Commission on Excellence in Education (*A Nation at Risk: the Imperative for Educational Reform*);[1] the Education Commission of the States (*Action for Excellence: A Comprehensive Plan to Improve Our Nation's Schools*);[2] the Business-Higher Education Forum (*America's Competitive Challenge: The Need for a National Response*);[3] the Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy (*Making the Grade*);[4] and the Carnegie Foundation for the Advancement of Teaching (*High School*).[5] In addition to emphasizing the obstacles represented by shortages of equipment and qualified instructors—particularly in science and math—these reports point to the low student participation rates in science and math beyond the 10th grade, the high levels of functional illiteracy within the general population, and the implications these conditions have for continued U.S. economic growth and participation in a world economy that is increasingly technology-driven. The reports of the National Commission on Excellence in Education, the Education Commission of the States, and the Business-Higher Education Forum all recommend a reassessment of the U.S. educational system and curricula in light of changing world conditions, including the growing use of advanced technologies in the workplace.

Given current levels of concern over the U.S. competitive position and the links between continued development of the human resource and sustained economic growth, it is difficult to understand why the relationship between education and training and economic expansion has recently become a focus of national attention—especially since the effects of education on the labor force have been the subject of economic analysis for many years. Part of the answer may lie in traditional economic measures used to quantify returns on educational investment. These measures examine the relationship between different levels of educational attainment and lifetime wages, without taking into account all other influences on lifetime wages:

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[1] National Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform* (Washington, D.C.: U.S. Government Printing Office, April 1983).

[2] Education Commission of the States, *Action for Excellence: A Comprehensive Plan to Improve Our Nation's Schools* (Denver, Colo.: Education Commission of the States, June 1983).

[3] Business-Higher Education Forum, *America's Competitive Challenge: The Need for a National Response* (Washington, D.C.: Business-Higher Education Forum, April 1983).

[4] *Making the Grade: Report of the Twentieth Century Fund Task Force on Federal Elementary and Secondary Education Policy* (New York: Twentieth Century Fund, Inc., 1983).

[5] Ernest L. Boyer, *High School* (Princeton, N.J.: The Carnegie Foundation for the Advancement of Teaching, 1983).

> In the interest of precision, economic analysis has narrowed human contribution to its most measurable aspects such as wages and hours worked. So long as wages and other measurable evidence of human participation in the economy were on the rise, everything was fine. Interested parties, especially educators, were satisfied to know that rates of return to human investment were high and increasing as the economy boomed and wages and leisure increased. With economic decline and unprecedented demographic change, however, wage returns on human investment have headed downward. Those who swallowed the simplistic "human capital" assumption that wage returns capture the overall economic return to human resource development in good times are, unfortunately, hooked when the economy turns sour and wages decline. What we need is a more sophisticated means for measuring human quality and its impact on the economy. Unless we can find such a method, we will continue to miss the woods for the trees in assessing the relative importance of human factors in production.[6]

Regardless of how the human resource has been viewed as a factor in production, or how well its effects on the economy have been measured, industry, labor, and government leaders all recognize that a highly developed human resource pool is critical to maintaining U.S. competitiveness. Individuals will therefore place pressure on the U.S. instructional system for programs that develop human skills essential to continued work force participation.

The automated manufacturing environment represents but one of a number of work settings out of which new skill requirements will emerge in the years ahead. Therefore, it is important not to overemphasize PA-related skills to the neglect of other types of general and occupation-specific skills. The development of strong basic skills in math, science, and communication remains an important educational priority for the work force as a whole.* Given the increased use of computers in many aspects of American life, the demand for computer literacy programs is on the rise. In addition, there is a need to better prepare individuals for greater exposure to new technologies in their day-to-day lives, whether or not they choose to be work force participants. This involves the development of a basic understanding of scientific principles and processes, as well as of the relationships that exist within the physical world.[7] A recent report of the National Science Foundation's Public Understanding of Science Program made reference to:

> . . . the increasing gap between the relatively small technological elite and the far larger public that is both poorly equipped to understand new developments, and is effectively precluded from significant careers related to science, engineering and high technology. Thus, to maintain a vigorous and widely representative pool of potential talent for the technological professions; to assure a base of awareness and understanding among decision makers of industry, government, and the press; to encourage the interest and familiarity that are needed to recognize and address the personal and public decisions related to technology; and to meet the Jeffersonian ideal of an informed electorate, . . . an interest and background of experience with the principles and activities of science is critical.[8]

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[6] A. Carnevale, *Human Capital: A High Yield Corporate Investment* (Washington, D.C.: American Society for Training and Development, 1983), pp 13-14.

*Other priorities include increased emphasis on foreign languages from elementary school onward and a renewed emphasis on humanities, particularly in interdisciplinary programs, such as "technology and society."

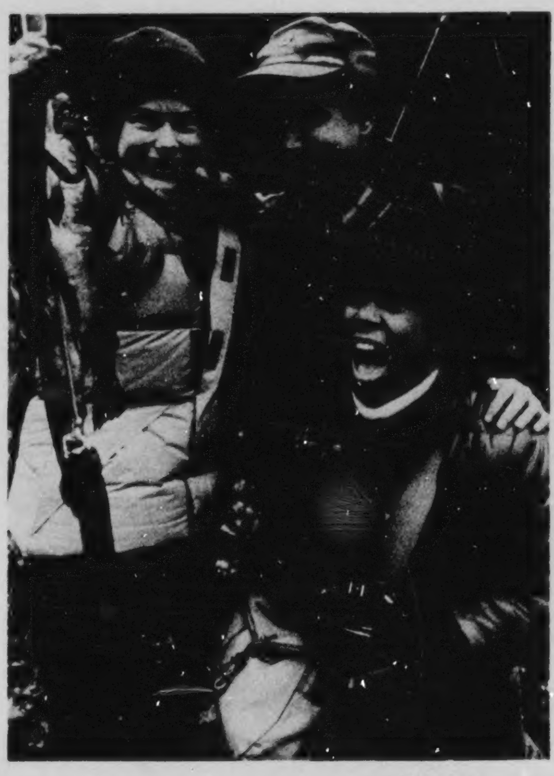
[7] E. Leonard Brown, "Educational Change: Educating for a Transitional Era," *Futurics*, vol. 7, No. 3, 1983, pp. 11-14.

[8] *Summary of Grants and Activities: Public Understanding of Science Program* (Washington, D.C.: National Science Foundation, March 1982), p. 4.

Effects of Programmable Automation and Other Technologies

OTA's analysis of employment effects of programmable automation indicates that computer-based manufacturing technologies will bring about substantial changes in manufacturing skill requirements over time. However, several variables complicate the process of quantifying long-term employment impacts. The most important of these variables are: 1) the rate at which programmable automation is adopted; 2) the flexibility afforded by PA to combine people and equipment in production in different ways; and 3) changing economic conditions affecting product demand, frequency of innovation, intensity of competition and, in turn, labor demand within automated manufacturing environments.*

Even at present low levels of utilization, programmable automation is creating new demands for education, training, and retraining services. In the future, with more widespread use of advanced manufacturing technologies, there will be considerable demands made on the U.S. instructional system for manufacturing-related skills development and for rapid responses to what may be frequent changes in skill requirements. For example, in a recent survey of members of the American Society for Training and Development's Technical and Skills Training Division, 93 percent of the respondents indicated that, based on technological change within their companies: 1) workers in their firms would require "significant changes in skills"on an ongoing basis, and 2) skill changes would typically be required within a relatively short time frame—possibly less than 1 year.[9] Programmable automation will also stimulate renewed demands for the development of strong, basic skills in reading, math, and science that serve as the foundation for PA-related instruction. While some things are known about the effects of PA on skills requirements, other things remain, at least for the time being, unknown—since they will be the outgrowths of future modes of adoption and methods of application.



Adventurous Hosts: 3-2-1 CONTACT'S young hosts Kathy (Kelly Pino), Miguel (Frank Gomez), and Robin (Judy Leak) traveled over 30,000 miles to 80 different locations around the country in search of adventures that bring excitement of science alive for young audiences. This Public Television System series is one of a number of projects funded in part by the National Science Foundation's "Science for Public Understanding Program." 3-2-1 CONTACT is now the second most popular program on public television. For more information on this NSF Program, see p. 221

The challenge for educators and trainers will be to design and deliver instruction that develops skills with which individuals can better deal with the unknown—i.e., with future

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*For a more detailed discussion of impacts on employment and effects on working environment, see chs. 4 and 5.

[9] *Survey of Technical and Skills Training Division*, American Society for Training and Development, 1983.

changes in skill requirements brought on by possible increased use of PA and other factors. Instruction designed to accomplish these ends involves the development of: 1) strong basic skills in reading, math, and science; 2) analytic and problem-solving skills, which enhance an individual's ability to operate effectively in new or modified work environments; 3) a broad occupational skills base which in turn broadens individual career choices and serves as a foundation for the development of additional skills; 4) specific PA-related skills; and 5) a recognition of the need for lifelong instruction to facilitate continued participation in and advancement within the work force. This new, future-oriented approach to education and training allows skill levels to advance at a rate more in keeping with the rate of technological change and stresses the need for flexibility to handle frequent job changes within the same sector or from one sector to another. However, its central focus is on **more extensive development of individual potential.** It can help preserve or enhance mobility, reducing the chance that workers are locked into, or out of, certain types of work as technologies and the economy undergo change.

This approach to instruction represents a blending of guiding principles from two traditional but disparate schools of thought on the ultimate goal of instruction: "education for work" (focus: occupational preparation) and "education for life" (focus: education for individual development). It also softens the sharp distinctions educators and others have drawn over the years between vocational/technical education and professional education, for it stresses the importance of analytic and problem-solving skills and of broad-based occupational preparation in both kinds of instructional experiences.*

Roles for Instruction in a Changing Society

The combined effects of technological and economic change are now observable in many areas of U.S. society. But technological and economic change are also having pronounced effects on the expectations **individuals** and **employers** have for instruction as a tool for personal and professional growth. These expectations take the form of increased demands for specific kinds of instructional programs and services. Accelerated growth in new course offerings, heightened interest among educators and trainers in curriculum development, and new skill requirements or skill shortages expressed by industry are all evidence of these increased demands. Some of the new instructional demands emerge from changing skills requirements in particular working environments. Other instructional demands reflect the impact that technological and economic change is having on society as a whole, and as such cannot be attributed simply to factors present within the workplace. Regardless of the circumstances that result in new education, training, and retraining requirements, the institutions, organizations, and agencies that make up the instructional delivery system in the United States are called on to develop programs and services that are responsive to **both** individual and employer demands and to supply these programs and services on an as-needed basis. Given current and anticipated rates of economic and technological change, plus the resources presently available to instructional providers for use in addressing demand, individual and employer expectations of the instructional system are not realistic and the full set of demands cannot be met. An abstract discussion of representative individual and employer expectations for instruction, as well as of conditions currently

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*The sharp, post-World War II increase in the amounts of corporate, in-house technical and skills training activities has had an influence on the nature and scope of some types of vocational instruction. Instructor and equipment costs associated with technical and skills training for employees, as well as narrowly defined production line jobs, have led to the development of in-house training that is often very narrowly focused and designed to develop only those skills required for discrete clusters of skills. While this approach to skills instruction has worked well for industry in many instances, it has influenced vocational education as a whole by leading to a deemphasis on analytic and problem-solving skills development and a movement toward highly specialized instruction. For a discussion of how high technology is affecting both the process, content of, and planning strategy for vocational and technical education, see Warren H. Groff, "Impacts of the High Technologies on Vocational and Technical Education," *ANNALS, AAPSS*, No. 470, November 1983, pp. 81-94.

faced by instructional providers, will establish themes that will be examined in greater detail later in this chapter.

Individual Expectations

OTA found that individuals are concerned about how economic and technological change will affect them directly—about the potential for more frequent job or career changes over a lifetime, and about the changes in skills requirements that seem likely to occur within and across established occupations.* Given the recent, extensive media coverage of factory and office automation, individuals now in the work force and those preparing to enter it are particularly sensitive to the potential for technologically induced skills changes. An operator of a flexible manufacturing system, interviewed in the course of an onsite investigation of working conditions in an automated plant of an agricultural implements manufacturer, put it this way: "If you're looking at 15 years or so before retirement, you'll be sweeping floors."

Regardless of their age or economic status, individuals who make the connection between continued skills enhancement and continued employment want access to instruction that makes the most of their previous training, their core skills, and that corrects basic skills deficiencies that may be interfering with the development of additional skills and proficiencies. These individuals—young people preparing for careers, or adults now employed or recently displaced—also need access to reliable information on skills and occupations in demand, plus assistance in determining what types of instruction will adequately prepare them to compete for available jobs and maintain employment. They also seem less willing than in the past to assume that educators, trainers, and career counselors know what is best for them.

Employer Expectations

OTA found that many employers, aware that economic and technological change will affect their operations and their competitive position, are placing increased emphasis on efficiency and productivity. While employers can influence how advanced automation affects workplaces,* they are concerned about how the use of advanced automation may change skill requirements and how these new skills will be developed in current and future personnel. This concern derives, in part, from documented problems of basic skills deficiencies in the current work force and in the U.S. population as a whole.** Employers often hold different views from those of educators on the goals of instruction that occurs prior to employment. The Center for Public Resources polled representatives of industry, labor, and the educational community on how well local school systems prepare individuals for work, as well as on specific competencies based on basic math, science, and communications skills. Survey results revealed a great disparity between industry, labor, and educator views of what constitutes "work-readiness" and what types of baseline competencies employers have a right to expect of employees. The industry/labor respondents had much higher expectations in the area of practical, basic competencies than did the educators.[10]

Regardless of economic sector or geographic location, it is clear from statements employers have made in various public forums, including congressional hearings, that many want an instructional system that produces individuals who have a strong foundation of reading, math, science, and communications skills; who possess core occupational or professional skills; and who have acquired analytic and problem-solving abilities that will enable them to better adapt to workplace change. In general, employer and individual demands are quite similar, with the exception of the emphasis employers place on analysis and problem-solving abilities.

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*This discussion of individual expectations is based on analysis of education and training literature, numerous discussions with employees in the course of site visits to industrial facilities, and conversations with students enrolled in a variety of education and training programs.

*For a detailed discussion of PA-related working environment issues, see ch. 4: "The Effects of Programmable Automation on the Work Environment."

**The concern for basic skills deficiencies in the general population was first brought to light in 1975, with the release of *Adult Performance Level Study*, the final report for a 4-year study conducted by the University of Texas for the U.S. Office of Education. The report indicated that nearly 20 percent of the adult population of the United States was functionally illiterate and, because of basic skills deficiencies, unable to perform common daily functions such as writing checks, shopping for food, or ordering a meal in a restaurant.

[10] *Basic Skills in the U.S. Work Force: The Contrasting Perceptions of Business, Labor, and Public Education* (New York: Center for Public Resources, November 1982).

Instructional Providers

At the same time individuals and employers are demanding more from education, training, and retraining programs and related services, the U.S. instructional system is facing unprecedented obstacles—including shortages of instructors in science, math, and technical fields such as engineering; facilities with limited capacities relative to demand; and outdated equipment. This is true for nearly all of the entities that are engaged in the design and delivery of technical instruction, including industry and labor. Educators in publicly supported elementary, secondary, and postsecondary institutions feel constrained by reduced Federal assistance and lower State and local revenues being channeled into instructional programs. Industry-based human resource development personnel, especially those who operate within older industries such as auto, steel, and rubber, are being forced to reevaluate their approaches and programs. They are facing decisions of whether to expand in-house course and program offerings in the face of low profit margins, reduced capital investments, and increased foreign competition—conditions that usually precede a reduction in corporate-sponsored instructional programs—or to attempt to identify other sources of instruction for their personnel.

Labor unions, while successful in negotiating some agreements that call for the establishment of joint union-management training funds for workers on the job and for those who have been laid off, now only represent about 20 percent of the U.S. work force.* Even in industries within which the majority of workers are unionized, unions are operating under conditions more conducive to concessions than to new demands. In addition, for unions and for industry, there is a basic uncertainty about how current instructional programs should be revised or expanded to reflect the increased use of advanced technologies and changing skill requirements, given the ongoing nature of technological change.

Categories of Instruction

In discussing how technological and economic change are affecting instruction, it is important to examine the types of instructional experiences available to individuals.

OTA found that most instructional services fall into one of four categories:

1. **Education**—initial preparation for work and for life;
2. **Training**—instruction received upon entry to the work site that bridges the gap, if any, between skills developed through formal education and skills required to function effectively in the workplace;
3. **Retraining**—all other forms of work-related instruction, including professional development and skills upgrading; and
4. **Continuing Education**—instruction that is not necessarily directly work- or career-related, but often geared to personal development.

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*Such funds require contributions from employers and individuals. For example, the Los Angeles Electrical Training Trust was established in 1964 to support education and training programs for apprentices and journeymen covered under the collective bargaining agreement between the International Brotherhood of Electrical Workers' Local 11 (IBEW) and the Los Angeles Chapter of the National Electrical Contractors' Association. Under the terms of the agreement, Local 11 members contribute to the Trust 5¢ for every hour worked, while their employers contribute 15¢ for every employee hour worked. (For more information, see the IBEW case study included in app. A to this report.)

Clearly this range of services, or experiences, constitutes in its fullest form a lifelong program of education. While lifelong education has been talked about in educational circles for a number of years, the combined influences of technological and economic change are making the need for lifelong learning a reality for the current and future work force, regardless of the skill level considered. Individuals are coming to realize that, regardless of their level of educational attainment prior to joining the work force, there are no guarantees of lifetime employment.[11] Workplace change can trigger frequent modifications in job functions, or necessitate job changes or career changes that will require the development of new or enhanced skills. Many individuals may find it necessary to undergo education, training, and retraining several times during their lifetimes. Some of these individuals may get tuition assistance and permission to pursue coursework during working hours from their employers; others may have to draw on their own time and resources. Others may qualify for participation in federally funded training programs or for Federal student loans. Accelerated change in workplace conditions will also increase the emphasis on quality of instruction (e.g., curriculum content, qualified instructors, adequate equipment and facilities) and related services, such as educational and job counseling. It will also generate greater pressure for rapid response to frequent changes in instructional requirements.

Current Trends in Instruction

As stated earlier in this chapter, programmable automation is but one of many forces leading to the development of new instructional priorities. It is important to examine what is known about current enrollment patterns and then to focus on new areas of emphasis for the U.S. instructional system as a whole. These conditions establish the context for a discussion of PA-related instruction and an evaluation of the capacities of the education and training system.

Changes in Enrollment

Patterns of participation in education, training, and retraining programs have changed over the past few years. Population groups served by different types of instructional programs are changing. Adults aged 17 years and older with specific personal or occupational goals are participating in education, training, and retraining programs in record numbers. This is in sharp contrast to earlier periods, when the heaviest levels of participation in instruction were found among children and adolescents. These earlier participation rates and patterns reflected the predominant view of the function served by instructional programs—formal education preceded employment and usually ended when an individual entered the work force.

According to the National Center for Education Statistics (NCES), elementary and secondary school enrollments declined by 13 percent between 1971 and 1981. In roughly the same period, enrollments in higher education (2- and 4-year institutions) continued to grow (see fig. 18). Full-time postsecondary students and all those enrolled in 4-year colleges and universities represented only 58.3 percent of total enrollment by 1982. This is attributed to the expansion of public 2-year colleges during this period whose programs were often characterized by open admissions policies, flexible class schedules, and perhaps a greater interest in the part-time, working student. During the period 1970-81, there was evidence of a shift in enrollment from 4-year schools to 2-year institutions, with enrollments in 4-year schools dropping from 74 percent to 62 per-

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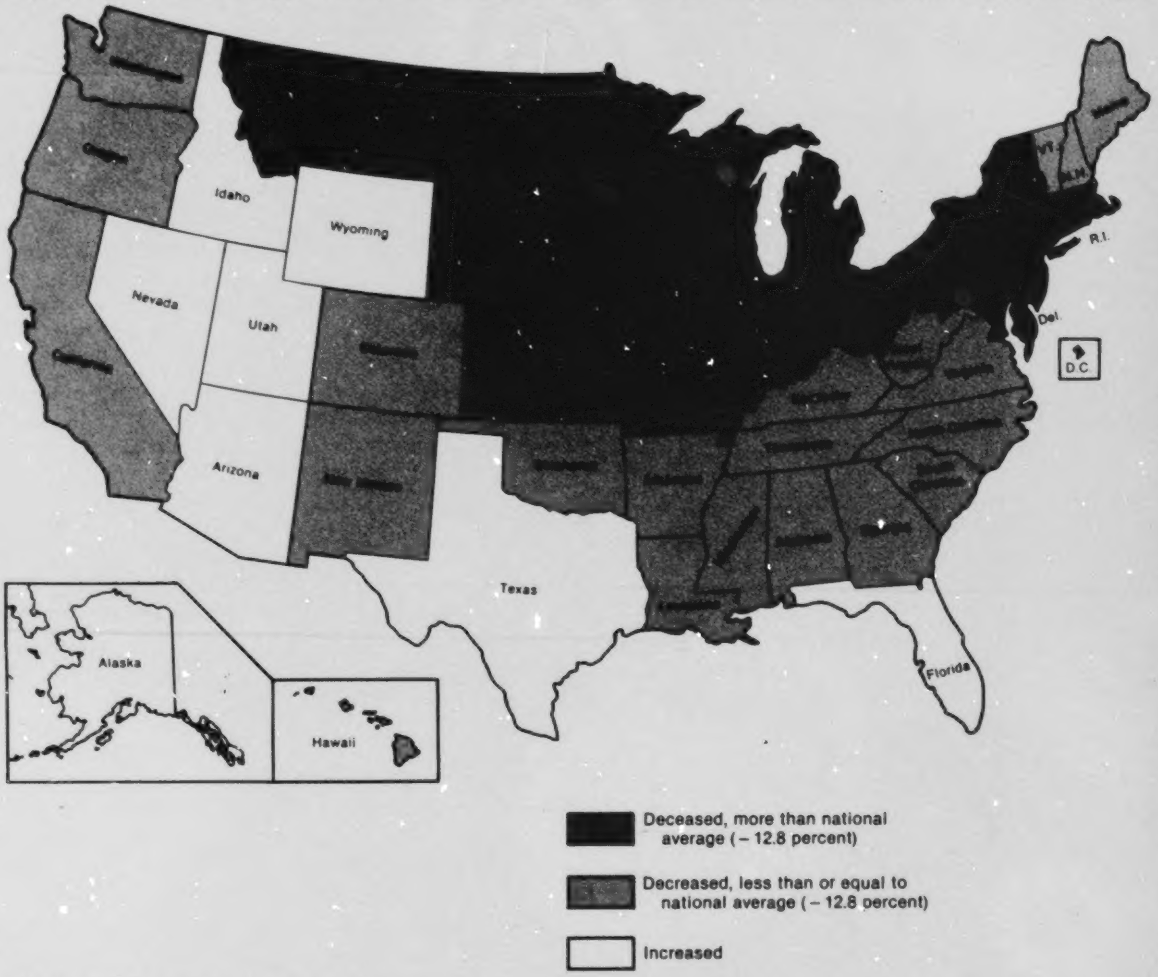
[11] Samuel Brodbelt, "Education as Growth: Life-long Learning," *The Clearing House*, vol. 57, October 1983, pp. 72-75.

Figure 18.—Percent Change in Public Elementary/Secondary School Enrollment Between 1971 and 1981, by State


Idaho
Wyoming
Nevada
Utah
Arizona
Texas
Florida
VT.
N.H.
R.I.
Del.
D.C.
Alaska
Hawaii
■ Deceased, more than national average (– 12.8 percent)
▨ Decreased, less than or equal to national average (– 12.8 percent)
☐ Increased

SOURCE: National Center for Education Statistics, 1982.

cent (see table 53 and fig. 19). During the same period, female participation in higher education grew steadily, while male enrollment remained fairly stable. Minority enrollment reached 16.5 percent by the fall of 1980: 9.4 percent of postsecondary students were black and 4.0 percent Hispanic.[12] These data suggest that postsecondary institutions are now serving a much broader audience and, perhaps, a wider variety of instructional needs. Shift in

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[12] *The Condition of Education, 1983 Edition* (Washington, D.C.: National Center for Education Statistics). During 1981-82, there were 3,253 institutions of higher education operating in the United States. Of this number, about one third, or approximately 1,200, were 2-year colleges. Institutions that specialized in 4-year, baccalaureate-level programs and that did not demonstrate significant involvement in post-baccalaureate education numbered 730. While the vast majority of 2-year colleges were public institutions (933), only 607 4-year colleges, were privately controlled (see table 53 and fig. 19). There were 167 institutions that offered doctoral programs, and another 408 institutions that offered post-baccalaureate programs other than doctoral programs. Some 545 institutions were classified as "specialized" by NCES, in that they placed emphasis on a particular program area, such as engineering. The majority of specialized institutions were privately controlled and offered baccalaureate programs, post-baccalaureate programs, or both. In the "new institution" category, 2-year schools have dominated since the 1960's.

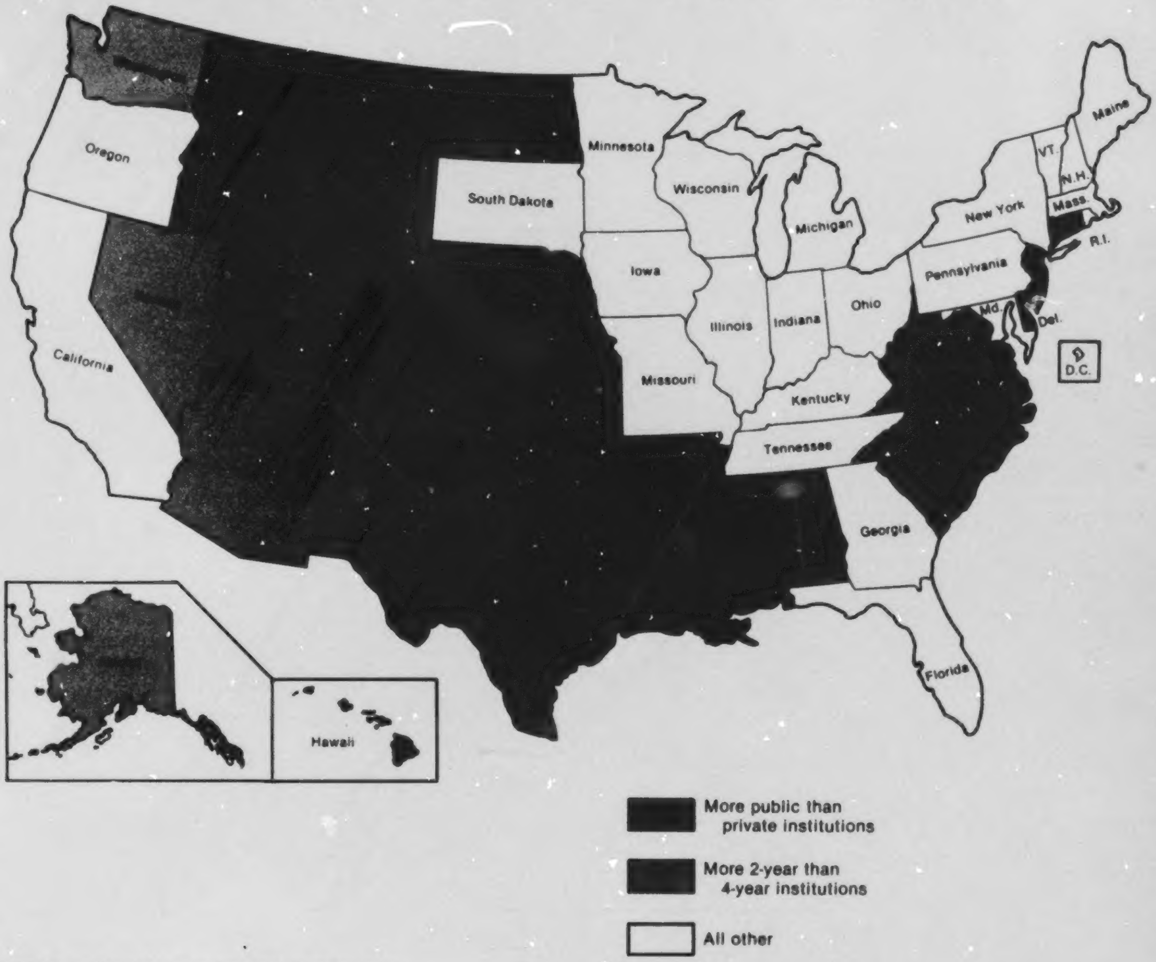
Table 53.—Number of Institutions of Higher Education and Branches by Level, Control, and State: Academic Year 1981-82

State	Total	All Institutions		4-Year Institutions		2-Year Institutions	
		Public	Private	Public	Private	Public	Private
50 States and D.C.	3,253	1,498	1,755	558	1,420	940	335
Alabama	59	37	22	16	15	21	7
Alaska	15	12	3	3	3	9	0
Arizona	28	19	9	3	8	16	1
Arkansas	35	19	16	10	10	9	6
California	272	136	136	30	123	106	13
Colorado	45	27	18	18	15	14	3
Connecticut	47	24	23	7	19	17	4
Delaware	8	5	3	2	3	3	0
District of Columbia	19	1	18	1	18	0	0
Florida	81	37	44	9	35	28	9
Georgia	78	34	44	18	29	16	15
Hawaii	12	9	3	3	3	6	0
Idaho	9	6	3	4	2	2	1
Illinois	158	63	95	13	83	50	12
Indiana	74	28	46	13	37	15	9
Iowa	60	21	39	3	34	18	5
Kansas	52	29	23	8	20	21	3
Kentucky	57	21	36	8	22	13	14
Louisiana	32	20	12	14	11	6	1
Maine	29	12	17	7	13	5	4
Maryland	56	32	24	13	21	19	3
Massachusetts	118	32	86	15	65	17	21
Michigan	91	44	47	15	41	29	6
Minnesota	70	30	40	10	32	20	8
Mississippi	41	25	16	9	10	16	6
Missouri	89	28	61	13	54	15	7
Montana	16	9	7	6	4	3	3
Nebraska	31	16	15	7	13	9	2
Nevada	7	6	1	2	1	4	0
New Hampshire	26	11	15	3	11	8	4
New Jersey	61	31	30	14	26	17	4
New Mexico	19	16	3	6	3	10	0
New York	294	86	208	40	168	46	40
North Carolina	127	74	53	16	34	58	19
North Dakota	17	11	6	6	4	5	2
Ohio	136	59	77	18	62	41	15
Oklahoma	44	29	15	14	11	15	4
Oregon	45	21	24	8	21	13	3
Pennsylvania	202	61	141	24	108	37	33
Rhode Island	13	3	10	2	9	1	1
South Carolina	60	33	27	12	19	21	8
South Dakota	20	8	12	7	9	1	3
Tennessee	79	24	55	10	40	14	15
Texas	156	98	58	39	52	59	6
Utah	14	9	5	4	3	5	2
Vermont	21	6	15	4	14	2	1
Virginia	69	39	30	15	28	24	2
Washington	50	33	17	6	16	27	1
West Virginia	28	16	12	12	8	4	4
Wisconsin	64	30	34	13	30	17	4
Wyoming	9	8	1	1	0	7	1
U.S. Service Schools	10	10	0	9	0	1	0

NOTE: Branch campuses are counted separately.

SOURCE: National Center for Education Statistics, 1982.

Figure 19.—Level and Control of Institutions of Higher Education, by State


Oregon
California
South Dakota
Minnesota
Wisconsin
Michigan
Iowa
Illinois
Indiana
Ohio
Missouri
Kentucky
Tennessee
Georgia
Florida
New York
Pennsylvania
VT.
N.H.
Maine
Mass.
R.I.
Md.
Del.
D.C.
Hawaii
More public than private institutions
More 2-year than 4-year institutions
All other

SOURCE: National Center for Education Statistics, 1982.

enrollment from 4- to 2-year programs may reflect the overall growth in demand for technicians (see ch. 4 of this report), since formal educational preparation for technician careers is typically a 2-year associate degree program.

Enrollment in vocational education reached 16.9 million during 1980-81. Among secondary institutions offering vocational education programs, there were 10.5 million enrollments, while postsecondary institutions that were regionally accredited, State approved or classified as "other postsecondary" by the Vocational Education Data System, accounted for a total of 6.4 million enrollments. The most recent information on the types of institutions offering vocational education programs is for 1978-79. Among secondary institutions offering vocational programs, public secondary schools, area vocational centers, and secondary-level adult programs accounted for the largest share of the 19 million enrollments for that period. By contrast, there was much less diversity in postsecondary institutions with significant enrollment levels, with 2-year institutions accounting for 68 percent of all enrollments (see fig. 20). Male and female participation rates in secondary-level vocational education programs varied according to enrollment areas, with females outnumbering males in programs for office occupations and males predominating in trade and industrial programs. Within high schools, there were higher proportions of blacks, Hispanics, and other

Figure 20.—Estimated Enrollments in Vocational Education, 1978-79

Secondary

1 + 2 Public secondary schools (including secondary level adult programs): 12,513,000

3 Private secondary schools: 22,000

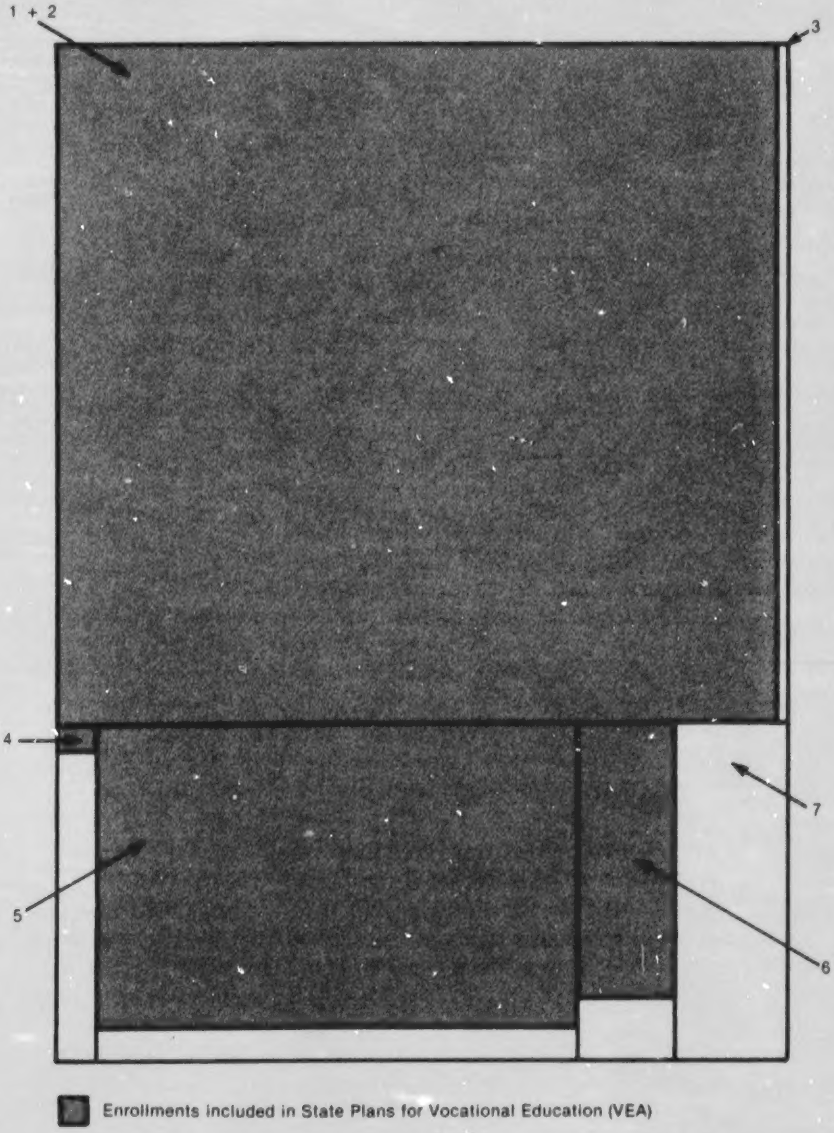
Postsecondary

4 4-year institutions of higher education: 309,000

5 2-year institutions of higher education: 4,423,000

6 Public noncollegiate postsecondary schools: 741,000

7 Private noncollegiate postsecondary schools: 989,000



▨ Enrollments included in State Plans for Vocational Education (VEA)

SOURCE: National Center for Education Statistics.

minorities enrolled in vocational education programs than in precollege and other types of programs.[13]

The number of adults participating in part-time education programs (usually defined as a course load of 9 credit hours or less), both degree-credit and nonacademic, has risen over the last decade and is expected to continue to rise into the 1990's. According to the results of the 1981 Adult Education Participation Survey, at the close of the year ending May 1981, over 21 million persons age 17 or older were enrolled in **adult education** programs, representing an increase of over 3 million since 1978, or 17 percent. As was the case in earlier surveys of adult education, the participation rates of whites were markedly higher than those of various other racial/ethnic groups. Whites represented 88 percent of all those engaged in adult education activities.[14] Individual level of prior education attainment continued to be one of the strongest factors influencing participation in adult education.* Income level was another key factor.**

Work-Related Instruction

By 1981, approximately 83 percent of those indicating participation in adult education were in the work force—some 17 million people. Of these, 70 percent held white-collar positions, including professional and technical jobs. The 21 million individuals participating in adult education activities in 1981 had over 37,000 courses from which to choose. Close to half of the courses they took were within the fields of business (23 percent), health (14 percent) and engineering (10 percent), and approximately 60 percent participated for job-related reasons. For 42 percent of the men and 26 percent of the women, employers provided some or all of the tuition. Expenditures for adult education in 1981 totaled $2.2 billion; the average expenditure per participant per course was $120. Approximately 54 percent of the adult education courses were provided by schools; the remainder were offered by industry, community organizations, government agencies, and others.[15]

Industry and Labor-Provided Instruction

Two important components of the U.S. instructional system whose activities are not fully captured in the description of enrollments provided above are industry and the labor movement. While there are no data on total enrollment in industry-based instructional programs, the American Society for Training and Development estimates that the private sector spends between $30 billion and $50 billion annually on such programs.* Unpublished Bureau of Labor Statistics (BLS) estimates suggest that in 1982 there were 287,000 persons enrolled in apprenticeship programs in the United States. This represents a decline of 33,000 since 1980.** While apprenticeship represents only one of a number of types of training offered by industry in cooperation with labor unions and labor organizations, there are no data available to measure the degree of labor involvement in nonapprenticeship instruction.

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[13] National Center for Education Statistics, op. cit., 1983. According to NCES, some 27,000 different institutions offered vocational education programs in 1978-79. Over half of these institutions, or 15,700, were publicly funded comprehensive and vocational secondary schools. The second largest group of institutions offering vocational education programs, "private noncollegiate postsecondary schools," numbered 6,800 and included vocational/technical institutes and trade, health, and business schools. Also included among the providers of vocational education in 1978-79 were approximately 1,100 2-year and 600 4-year institutions.

[14] *Survey of Participation in Adult Education,* conducted by the Bureau of the Census for the National Center for Education Statistics, 1981.

*"For both 1978 and 1981, there was a direct positive relationship between the numbers of years of schooling and the rate of participation in adult education. Persons with an eighth grade education or less participated in adult education at a rate of only 2 percent in 1981. On the other hand, 31 percent of persons with more than 4 years of college had taken part in an adult education activity during the year. A little over 11 percent of high school graduates with no college experience participated in adult education, while over 26 percent of those with 4 years of college participated. The correspondence between higher educational attainment and greater participation in adult education was evident across all racial/ethnic groups, and was most notable among females. Within each racial/ethnic group, the more well-educated an individual was, the more likely he or she would participate in adult education activities. The relationship between greater attainment and participation was even more pronounced among females than among males. Male participation rates ranged from 2 percent for those with less than 9 years of formal schooling to over 28 percent for those with 5 or more years of college. While women with an eighth grade education or less participated at a rate of only 2 percent, those with 5 or more years of college participated at a rate of almost 36 percent, 8 percentage points higher than men with the same level of schooling." (National Center for Education Statistics, op. cit., 1983).

**In general, the higher the income, the greater the rate of participation. In 1981, the participation rate for those with incomes less than $7,500 was 6 percent, while approximately 19 percent of individuals with incomes of $50,000 or more participated. Adults residing in metropolitan areas comprised 72 percent of adult education participants. Participation rates relative to population were higher for the Western States (27 percent) than for the North Central States (approximately 14 percent), the Northeast (10 percent), or South (11 percent).

[15] National Center for Education Statistics, op. cit., 1983.

In summary, data available on enrollments in elementary, secondary, postsecondary, vocational, and adult education seem to show that while the numbers of participants under the age of 17 have been declining, there have been increases over the past few years in adult participation. However, given the high levels of educational attainment, high incomes, relative youth, and ethnic/racial makeup of those participating in instruction, **individuals within the work force who are at greatest risk due to technological and economic change are those least predisposed to enrolling in courses that may lead to new skills development.**

Changes in Emphasis

National recognition of the role that human resource development plays in continued economic growth is leading to changes in instructional priorities, especially for education and training that occurs prior to employment. New areas of emphasis that are already having an impact on curriculum are strong basic skills in math, science, and communication; and computer literacy.

Basic Skills

While there are skill requirements associated with particular workplaces that change over time, there are some types of skills so important that they are widely accepted as essential to individual and economic growth. Development of these skills within the individual serves as a foundation for higher order personal and career skills. Development of these skills is also necessary for exercising most rights of individual citizenship. The skills that comprise this group, commonly referred to as "basic skills," have changed over time to reflect economic, scientific, technological, and social change. Basic skills as currently defined are under national scrutiny to determine how viable they are and whether there are additional skills that are now so critical to individual and national growth that they should be added to the core group.

Since the Colonial era, the need for basic proficiencies in mathematics, reading, and writing has been recognized by educators as a central goal of instructional programs for children and adults. With the creation of a public education system in the United States during the 19th century, the goal was to provide to all school-age residents of the United States, including recent immigrants who represented a significant portion of the manufacturing work force during the Industrial Revolution, the opportunity to develop these skills or proficiencies. These basic skills were to be developed in the primary grades and were to serve as the foundation for both the vocational and academic tracks established as a part of the 19th-century public school system.[16] [17]

Following the reemphasis on basic skills at the founding of the public education system, the next major reexamination of basic skills and their relation to occupational preparation occurred in the 1950's, when increased concern over national defense and a national commitment to manned space exploration led to the enactment of the National Defense Education Act.* This legislation encouraged secondary and postsecondary institutions to place additional emphasis on the development of strong science and math skills. The act also sought to increase the supply of scientists and technical personnel through individual scholarships and low-interest loan programs. During this period, recognition of the increasing importance of the sciences for vocational and occupational preparation and for understanding key national issues led to a redefining of "basic skills" to include a foundation in the sciences. And for a time, the development of strong basic skills in this broader sense was a national priority.

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*This is a rough estimate of the total, annual industry expenditure. ASTD is cooperating with the Department of Labor (DOL) to establish mechanisms for systematically gathering data on industry-based education and training activities.

**The program for tracking the numbers of registered apprentices on an ongoing basis was eliminated as a result of DOL budget reductions and program reorganization in fiscal year 1982.

[16] Lawrence A Cremin, *Public Education* (New York: Basic Books, Inc., 1976).

[17] Sol Cohen, "The Industrial Education Movement, 1906-17," *American Quarterly*, vol. 20, No. 1, spring 1968, pp. 95-96.

*Some would argue that basic skills deficiencies that surfaced during World War II among American military recruits led to another national examination of how basic skills were being addressed in elementary and secondary education.

It is difficult to determine exactly when emphasis on the development of strong basic skills diminished. However, employers began to voice concerns about basic skills deficiencies in entry-level personnel in the early 1970's.

The change in emphasis on basic skills may have been related to the broad range of social issues that affected the educational system beginning in the mid-1960's. The list of mandates for the public education system grew rapidly in the late 1960's and 1970's. Educational equity emerged as a top priority as a result of the urban crisis, recognition of high levels of unemployed minority youth, and the passage of Federal legislation requiring school desegregation. With the passage of the Elementary and Secondary Education Act, the public schools were charged with ensuring that equal educational opportunity was extended to various target populations, including minorities, the economically disadvantaged, and the handicapped. Perhaps with the resources and attention directed at this and other important new educational priorities, federally funded educational institutions may have inadvertently deemphasized basic skills development. Changing societal goals and values, as well as changing demographics, have presented challenges to educators since the turn of the century. And, at present, schools are caught between the requirements of an old society, with its inherent goals and values, and the requirements of an emerging, more technological society.[18]

Computer Literacy and the Basic Skills

In the 1980's, continued advances in information and communications technologies and the growing use of computers in the workplace, in education, and in the home have created an awareness of the value of a "computer literate" population. Computer literacy as a term came into use in the mid-1970's. Since that time, there have been a variety of interpretations of what it means to be "computer literate."[19] [20] While computer literacy can encompass varying levels of knowledge of computer technology, it usually refers to basic keyboard skills, plus a working knowledge of how computer systems operate and of the general ways in which computers can be used. For example, Boeing Computer Services, a firm that offers nationally a range of courses relating to computer technology, covers the following topics in its "Personal Computer Literacy" course:

- computer terminology;
- computer manuals (documentation);
- computer keyboards;
- diskette organization;
- computer files; and
- general operating practices.

Based on the variety of environments within which individuals are affected by computer technology, as well as the importance of promoting understanding of science and technology within the general population, educators and others are once again revisiting the definition of "basic skills" and determining whether it should be expanded to include computer literacy.

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[18] William K. Elser, "The American School Dilemma: On the Upside of the Third Wave," *The Clearing House*, October 1983.

[19] Ronald E. Anderson, "National Computer Literacy, 1980," *Computer Literacy: Issues and Directions for 1985* (New York: Academic Press, 1982).

[20] Dorothy K. Deringer and Andrew R. Molnar, "Key Components for a National Computer Literacy Program," *Computer Literacy: Issues and Directions for 1985* (New York: Academic Press, 1982).

Critics of computer literacy as an instructional priority question its value to the population as a whole; they cite continuing advances in software technology that will increase ease of computer use and eliminate the need for formal instruction. For example, alternative input devices such as the light pen, the "mouse," and voice command are now becoming available and are particularly popular with workplace personnel who are uncomfortable with keyboarding, such as managers.[21] In addition, a major obstacle to achieving widespread computer literacy continues to be the high level of functional illiteracy in the U.S. population. Most recent estimates indicate that one out of five Americans lacks sufficient reading, writing, and math skills to perform such common, day-to-day functions as filling out a job application or handling personal finances.* The business community has become increasingly concerned about basic skills deficiencies among employees, including college graduates. These deficiencies represent major obstacles to professional performance as well as to continued professional advancement. In a recent survey of representatives of industry, trade unions, and local school systems, two-thirds of the industry representatives and the majority of the union representatives indicated that basic skills deficiencies in employees limit advancement opportunities. And, while the survey indicated that a variety of cooperative activities existed between industries and schools, there were few cooperative programs aimed specifically at basic skills development.[22]

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[21] Craig Zarley, "The Wide World of Alternative Input Devices," *Personal Computing*, February 1984, pp. 129, 131, 133-34, and 137.

*See reference to University of Texas study of adult illiteracy cited earlier in this chapter on p. 224.

[22] Center for Public Resources, op. cit., 1982.

Challenges Facing the U.S. Instructional System

Instructional providers are being asked to take on an increasing number of responsibilities relating to human resource development. First, they are faced with continuing efforts to upgrade the skill levels of the U.S. population as a whole—specifically through the development of basic language, reading, math, and science proficiencies. At the same time, they are charged with addressing the need for developing new skills and capacities, such as computer literacy and a basic understanding of science and technology within the general population. In addition, they must continually review programs and services relating to vocational and professional development in the light of economic and technological change. It is within this context that the instructional requirements for programmable automation must be examined.

Instructional Requirements for Programmable Automation

Some of the education, training, and retraining requirements linked to the use of programmable automation in manufacturing **cannot be distinguished** from instructional requirements linked to the increased use of advanced information and communications technologies in nonmanufacturing work settings—e.g., the need for a strong foundation of basic skills and for computer literacy is also linked to the use of computer-based technologies in public and private sector office work sites. Other current impacts on the U.S. instructional system are **directly attributable** to programmable automation and its effects on skills within existing manufacturing occupations—those within the production-line, technician, engineering, and operations management groups. It is this distinct set of PA implications for vocational and technical education, training, and retraining that will be the focus of this section of the chapter.

It should be noted that certain conditions limit this discussion of instructional requirements for PA. First, advanced manufacturing technologies are now in limited use. While PA adoption will increase, patterns of use to date have not led to investigations of skill requirements and accompanying instructional needs that go beyond what may be unique requirements of individual firms. Secondly, the literature on PA-related skills and on instruction for automated manufacturing environments is thin, consisting almost entirely of very general descriptions of individual courses or programs. Because of these limitations, observations made in this section of the chapter on instructional needs for PA are based in part on 14 in-depth case studies of 20 existing instructional programs that were prepared for OTA in conjunction with this assessment.

Instructional Requirements for Production Line Skills

For jobs common to production work in automated facilities, there appears to be a greater need to develop the ability to apply conventional manufacturing skills in new, more conceptual ways. For example, in a Cincinnati Milacron, Inc. (CMI) training program for employees of firms that purchase CMI's computerized numerical control (CNC) equipment, operators learn to interact with the control panel and to monitor rather than constantly interact with the equipment. CMI instructors stress that while students, especially older machinists, need to learn to use their knowlege of machine operations (conceptual) more than they may have in the past, their knowledge of traditional machining operations (motor) will enable them to anticipate CNC machine motions and functions.[23] Overall, electronic control of production machinery of all types is expected to reduce demand for **motor skills** and increase the demand for **conceptual skills.**[24]

Instruction for some technician-level occupations is quite similar in some instances to instruction for skilled trades occupations (e.g., electricians and electronic technicians), given the similarities between certain skilled trades jobs and selected technician-level jobs. But where distinctions can be drawn—e.g., for robotics, programmable equipment field service, and NC part programing technicians—the focus of technician-level instruction is now on the development of multiple skills (greater skill breadth) and of an understanding of how programmable equipment interfaces with other components of the manufacturing process.

Traditionally, limited employer-provided instruction has been made available to semiskilled and skilled production personnel beyond apprenticeship and/or entry-level training. PA has resulted in more emphasis on training for semiskilled and skilled worker groups. For example, like many other General Motors' facilities, the "S" Truck Plant examined in an OTA case study had had no formal mechanisms for delivering in-plant, classroom and laboratory training to shop floor workers prior to the installation of programmable equipment in 1980. Since the plant education and training department staff lacked the technical expertise to provide such instruction, training for shop floor workers took the form of on-the-job training or was provided by equipment vendors. The plant's "New Technology Training Program" established a permanent technical training group and created an awareness among plant management of the need for an in-plant training/applications lab that included equipment designated for training purposes.[25]

Production personnel responsible for equipment/systems operation, and/or maintenance and repair most often receive their training from vendors of programmable equipment and systems. Through these programs, production staff, along with all other types of manufacturing personnel, are oriented to general equipment/system features and operation. Rarely is the training designed to address the unique applications within a particular plant or facility.* There are exceptions among vendors, however. Cincinnati Milacron, for example, offers formalized customer training courses for its NC and CNC machines and robots, but will also develop instruction geared to particular customer applications and will provide training design consulting services on request.[26] All five companies studied who were producers of programmable equipment or systems —including Computervision, CADAM Inc., Cincinnati Milacron, Inc., GCA, and Automatix—provide informal on-the-job training to customers on an as-needed basis to supplement instruction provided at installation. Formal training programs range from 2½ days to 3 weeks.

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[23] Cincinnati-Milacron case study, 1983.

[24] Barry Wilkinson, *The Shopfloor Politics of New Technology* (London: Heinemann Educational Books, 1983).

[25] General Motors case study, 1983.

Both producer- and user-provided training for production personnel stresses how to operate, monitor, maintain, and repair programmable equipment or systems. In-plant courses examined which were provided by user firms were very narrowly focused and intensive, with training periods of 1 to 2 weeks.[27]

In some instances, PA-related training for skilled production personnel with some previous exposure to electromechanical technology is broader in scope. Presumably, these workers are graduates of apprenticeship programs and have broader skills on which to base instruction. For example, the International Brotherhood of Electrical Workers' Local 11 Electrical Training Trust in Los Angeles County, Calif., provides voluntary training to journeymen electricians on the installation and maintenance of programmable controllers. The training is designed to develop in enrollees who possess a background in electricity an understanding of electronics technology—a related but separate discipline.[28]

Community colleges take a variety of approaches to technician-level instruction for PA—from single courses to 2-year associate degree programs. Henry Ford Community College (HFCC) in the Detroit area offers an "Automation/Robotics Option" within its 2-year Electrical-Electronics Program. Among the subjects covered are programmable controllers and other computer-aided manufacturing (CAM) equipment. HFCC has also developed several courses on programmable controllers geared to the needs of union apprentices and journeymen. Glendale Community College in Los Angeles County operates a short-term industrial training program on computer-aided design (CAD) in conjunction with local industry and government. Both HFCC and Glendale encourage students to continue their education beyond the associate-degree level by indicating courses that could be applied to a 4-year bachelor of science degree.[29] [30]

There are some attempts under way to develop a standardized curriculum for technician-level occupations within the field of programmable automation. The advantage of the core curriculum is that it develops a broad foundation of knowledge on which to base subsequent PA instruction during the same instructional period or at a later date. For example, the Center for Occupational Research and Development (CORD), a nonprofit organization that develops instructional materials for emerging technical fields, has developed a core curriculum to which components for robotics, computer-aided drafting, or laser technology can be added. The core curriculum seeks to develop interdisciplinary skills, including:

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*This was one important finding of the OTA-sponsored survey of views of education, training, and retraining for programmable automation. For more information on the survey, see *Automation and the Workplace: Selected Labor, Education and Training Issues* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-TM-CIT-25, March 1983).

[26] Cincinnati Milacron case study, 1983.

[27] In-plant, user firm training was examined at the following companies/plants: 1) a large aircraft manufacturer (asked not to be identified); 2) Texas Instruments; 3) CADAM Inc., a subsidiary of Lockheed Corp. and a producer of computer-aided design software; 4) Cincinnati Milacron, a vendor of robots, computer-aided machine tools, and machine controls; 5) a General Motors' "S" Truck Plant; and 6) Westinghouse Corp.'s Defense and Electronics Systems Center.

[28] International Brotherhood of Electrical Workers case study, 1983.

[29] Henry Ford Community College case study, 1983.

[30] Glendale CAD/CAM Operator Training Program case study, 1983.

Photo credit: Los Angeles Electrical Training Trust

These skilled electricians, members of Los Angeles Local No. 11 of the International Brotherhood of Electrical Workers, are attending a 6-week training program designed to develop the skills required to install, troubleshoot, and maintain programmable controllers. Since the training program was first offered in October 1981, 170 members of the Local have completed the program offered by the Los Angeles Electrical Training Trust. Forty-six have completed an advanced programmable controller course. Graduates are employed by contractors who install and maintain automated equipment in manufacturing facilities. For more information on the Training Trust's programs, see app. A to this report, the section of this chapter entitled "Case Studies: Selected Instructional Programs," and p. 236 of this chapter

- electrical,
- mechanical,
- fluidal,
- thermal,
- optical, and
- microcomputer technology.[31]

Community colleges and vocational schools in several States—Ohio, Oklahoma, New Mexico, and Idaho—have adopted the CORD electromechanical curriculum as the standard for community colleges in their regions.

For the most part, PA instruction for technicians is developing along traditional lines. That is, PA-related courses are often simply added to existing curricula, such as electromechanical technology. While such programs may produce technicians qualified to operate in today's automated manufacturing facilities, they may or may not equip individuals for future workplace change. Programs that develop a broad interdisciplinary knowlege base, that emphasize computer technology, and that impart a broad understanding of the system as well as its components are essential if individuals are to have the flexibility to face future PA-related change in the workplace.[32] One program that seeks to develop this broad-based understanding of the system and components is a Brigham Young University (BYU) 4-year engineering technology program, which is described in detail in appendix A to this report.

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[31] Interview with Dan Hull, President, CORD, May 1983.

In two of the manufacturing facilities studied, Westinghouse Defense and Electronics Center and Texas Instruments, the training of shop floor personnel on automated equipment was linked to research and development activities. This link benefits researchers and production staff. Both firms have established manufacturing technology centers where the training of shop floor managers and workers who will utilize the technology once it is installed is conducted in conjunction with applications research. At both facilities, trainee involvement helps the researchers by providing information about shop floor-user needs and opportunities to test and utilize manufacturing technology in a practical environment. It also helps shop floor workers by allowing them to become familiar with the technology before it becomes a permanent part of the manufacturing process, and by enabling them to express their needs, concerns, and dissatisfactions prior to final system implementation.[33] [34]

Instructional Requirements for Engineers

Design and production engineers who work in computer-automated facilities are required to have a broader based knowledge of engineering operations and stronger management skills than those who work in more conventional manufacturing plants. There is also much greater emphasis placed on understanding how PA may be most effectively applied. In keeping with these new skill requirements, some engineering schools are placing greater emphasis on hands-on experimentation and project-oriented instruction and less emphasis on the more traditional, theory-based instruction.

For example, Worcester Polytechnic Institute (WPI), a primarily undergraduate engineering and science institution, joined forces with Emhart Corp. in 1981 to form an on-campus research center. In addition to providing Emhart and other firms with a manufacturing engineering applications research capacity, the center offers engineering students the opportunity for regular contact with practicing engineers and with practical problems and situations in the form of industrial "projects." Two projects—one focusing on an application within the student's major field and the other focusing on broad societal impacts of technology's application—are graduation requirements for all WPI students.[35]

BYU offers an engineering technology program with specialties in manufacturing, design, and electronics. All three of the BYU technology programs substitute application-oriented, laboratory-based courses for the highly theoretical coursework of traditional engineering programs. The goal is to combine a foundation in theory with practical applications experience. (See photo on p. 246.) Computer-aided design and manufacturing have been a part of BYU's engineering technology program since the mid-1970's.*

Attempts are being made on the undergraduate and graduate levels to familiarize design engineers with manufacturing requirements and, conversely, to familiarize production engineers with design procedures. In addition, there is more emphasis being placed on developing the ability to take the entire design-manufacturing process into account—e.g., through the systems approach, which focuses on the integration of computerized systems with more traditional forms of automation. Students enrolled in BYU's master's program in computer integrated manufacturing are required to have at least 1 year of industrial experience. They are free to pursue either CAD or CAM as an option within the program, but are required to take courses from each specialty area and learn to integrate computerized systems to solve practical, recurring industrial problems.[36] The University of Michigan's College of Engineering, although more traditional in its approach to undergraduate engineering education than some of the other schools studied, offers students a graduate-level program in integrated manufacturing. In 1981, the Engineering College established a Center for Robotics and Integrated Manufacturing (CRIM) in order to coordinate and expand research and teaching activities relating to computer-based automation. In 1982-83, a total of 45 graduate students participated in CRIM-sponsored research projects.[37]

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[32] Dan Hull, "What is High Technology?" *Developing High Technology Vocational Programs,* American Vocational Association and the Center for Occupational Research and Development, May 1983.

[33] Westinghouse Defense Electronics Center case study, 1983.

[34] Texas Instruments Corp. case study, 1983.

[35] WPI's Manufacturing Engineering Applications Center case study, 1983.

*A summary of the case study on BYU's Engineering Technology Program is included in app. A to this report.

The effects of programmable automation on engineering education will depend on the approaches taken to engineering instruction within individual educational institutions and programs. If the more traditional approach is taken on the undergraduate level—i.e., a focus on developing an extensive, theoretical framework on which to base practical experience—then PA will represent more of a force for change in graduate and continuing education programs. If individual institutions place greater emphasis on combining theory with practice in undergraduate engineering education, and in so doing emphasize CAD and CAM, then advances in PA research and applications will continue to trigger curriculum change on the undergraduate level. **The variety of approaches currently being taken to programmable automation in engineering education does suggest that individuals preparing for careers in engineering should be aware of the lack of standard approaches to curriculum content.** The mix of theory and application, as well as the exposure to programmable technologies, differs from school to school. Regardless of approach, a critical need for education is to ensure that engineering laboratories and curricula reflect the state of the art of the technology.[38]

Instructional Requirements for Managers

There has been concern within industry for some time about the lack of management expertise in technical personnel. Indeed, some observers suggest that industrial managers who are cautious and detail-driven, coupled with a corporate decisionmaking process that stresses short-term financial considerations over the potential for long-term gain, have substantially delayed redesign and retooling of the U.S. manufacturing sector.[39] Traditional engineering programs have not stressed the need for the development of management competencies, nor have traditional management education programs offered special courses geared to the needs of technical and engineering operations managers. A recent report of The American Assembly of Collegiate Schools of Business, the accrediting body and professional organization for the deans of approximately 600 undergraduate and postgraduate business schools in the United States, recommended that business schools address criticisms of overemphasis on finance and marketing in their curricula by giving equal weight to production processes and productivity.[40] Professor Tom Lupton, director of the Manchester Business School, University of Manchester (United Kingdom), who has conducted a study of management development programs in Western Europe, made these observations:

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[36] Brigham Young University case study, 1983.

[37] University of Michigan case study, 1983.

[38] Donald D. Glower and Lindon Saline, *A Response to Advancing Technologies: Repositioning Engineering Education to Service America's Future* (Washington, D.C.: American Society for Engineering Education, 1982).

[39] Wickham Skinner, "Wanted: Managers for the Factory of the Future," *ANNALS, AAPSS,* No. 470, November 1983, pp. 102-114.

[40] *Report on U.S. Productivity and International Competitiveness,* sponsored by The American Assembly of Collegiate Schools of Business at George Washington University, Washington, D.C., June 13-16, 1983.

> . . . Management education everywhere—in Europe and North America certainly—has suffered from the attempt to bring the world into the classroom rather than to take the teacher (or rather the organiser of learning) into the fields of action. However, it is encouraging to notice the beginning of a shift from the passive to more active modes of learning. . . . Yet although the shift is happening in many schools, movement is slow.[41]

The need for managers of automated manufacturing facilities and other complex operations to possess an understanding of the total manufacturing system and all of its components has led some universities to create new master's degree programs in technical management. The University of Pennsylvania's Wharton School has instituted a program entitled "Management and Technology"—a joint venture between Wharton and the University's Engineering School. The Sloan School of Management at MIT also offers a graduate program in the management of technological innovation. Yale University, too, has established an engineering management program on the graduate level—a joint venture between the engineering and management schools. And in the fall of 1983, BYU's Technology Department began to offer a graduate degree in technical management as a cooperative effort between the College of Engineering Sciences and the School of Management.*

Some universities are going beyond the disciplines of engineering and management to include an even broader base in their manufacturing engineering curricula. With the aid of a 4-year, $2 million grant from the IBM Corp., Lehigh University of Bethlehem, Pa., is launching a graduate-level manufacturing systems engineering program that will integrate "systems perspectives with interdisciplinary education and training" and combine academic coursework with "industry-oriented internships, laboratories, simulations, plant inspections and projects."[42] Lehigh is one of five universities benefiting from multimillion-dollar IBM grants to encourage the establishment of manufacturing systems engineering programs. UCLA's School of Engineering and Applied Science draws its graduate-level manufacturing engineering curriculum from the disciplines of materials science, mechanics and structures, computer science and engineering, electrical engineering, and engineering systems.[43]

Segments of the training industry and professional societies are also becoming aware of the interest in and need for technology management courses for engineers and nontechnical personnel employed in automated manufacturing facilities. Boeing Computer Services (BCS), a subsidiary of the Boeing Co.—a producer of commercial and military aircraft—is an established provider of technology-based training to commercial firms and Federal, State, and local governments. BCS is test-marketing a seminar for managers to provide them with information on the basics of CAD and CAM systems and related terminology; as well as a primer on computer graphics and the use of CAD and CAM software. Also covered in the seminar is a step-by-step approach to managing a CAD and CAM project, including:

- considerations for purchasing hardware,
- methods to ensure efficient system use to achieve maximum productivity,
- procedures for defining training requirements and implementing a training program,
- procedures for choosing proper systems applications for a particular environment, and
- procedures for establishing a data management system.[44]

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[41] Tom Lupton, *Management Development in Western Europe* (Manchester, U.K.: Manchester Business School, 1982).

*For additional information on this program, see the Brigham Young University case study, included in app. A to this report.

[42] B. Litt and M. Groover, *Developing Manufacturing Systems Engineers for the Future: A Unique Industry-University Joint Venture*, paper presented at the American Institute of Decision Sciences, Southwest Conference, Feb. 29, 1984.

[43] Vic Cox, "Materials Science and Manufacturing Engineering: The New Alchemy," *The Minority Engineer*, winter 1984, pp. 17, 20, and 22.

[44] Information provided by Boeing Computer Services, 1983.

To date, six courses have been delivered, with a total of 180 managers enrolled. Trade and professional organizations, such as the Society of Manufacturing Engineers, offer short courses in technical management to their members and other interested individuals, often in conjunction with national and regional conferences.

It is too soon to judge whether these technology management programs and courses constitute the beginnings of a trend. However, continued industry pressure for more effective technical managers may well lead to greater emphasis on the development of management skills in industrial engineering and computer science programs.

Case Studies: Selected Instructional Programs

The instructional system in the United States is a loose confederation of institutions, agencies, and organizations from the public and private sectors. The intent of the programs designed and delivered by these instructional providers varies widely. This is no less true for instructional programs that are designed to develop skills required in automated manufacturing facilities. Within this section of the report are included highlights of findings of an in-depth examination of 20 instructional programs for automated factory environments. These programs are representative of relatively successful efforts initiated by secondary and postsecondary educational institutions, vendors of programmable equipment and systems, users of programmable automation, labor unions, and Federal and/or State-funded retraining facilities. Cooperative instructional programs of various types are also featured. These findings also shed some light on the strengths and shortcomings of currently available instruction, problems encountered in program design and operation, and the roles assumed by educators, industry, labor, and government in these innovative efforts—roles that may be representative of emerging roles for these sectors within the instructional system as a whole.

To supplement this discussion of trends and patterns in PA-related instruction, appendix A to this report contains summaries of five of the case studies developed:

- a robotics and computer-aided drafting program for high school students, operated by the Oakland County school system in southeastern Michigan;
- the undergraduate and graduate degree programs in engineering technology offered by BYU, Provo, Utah;
- CADAM Inc.'s* customer training in computer-aided design;
- the Los Angeles Electrical Training Trust's programmable controller training program; and
- the "CAD/CAM" operator training program, at Glendale Community College, Glendale, Calif.

Appendix A also contains a brief description of the case study methodology.

Findings: Roles, Functions, and Capacities of Programs

The findings listed below are based on the universe of 20 programs encompassed in the 14 case studies. It should be emphasized that, even though careful consideration was given to ensuring variety and comprehensiveness of program types, the findings are limited by the size of the sample. Therefore, while certain general conclusions can be drawn, these are based solely on the scope of the programs investigated.

Primary Education.—One primary program was examined: the Dallas Independent School District's Project SEED. It emphasizes building basic mathematics skills and interest in mathematics as the foundation for further technical studies. Because the program can reach all school-age children in the district, it has the capacity to achieve an extremely broad impact by increasing the number of students capable of and interested in more advanced educational programs focusing on PA and other technological fields.[45]

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*CADAM Inc. is a subsidiary of Lockheed Corp.

High School Education.—Two high school programs were investigated: the Dallas Independent School District's Science and Engineering Magnet School; and the Oakland County, Mich., robotics and computer-aided drafting programs. Programs examined either focus on or include computer literacy, preengineering, basic computer science, computer-aided drafting, and robotics. Career awareness is also stressed. The programs examined indicate that PA studies can be introduced effectively at the high school level, especially if orientation to computer-aided techniques is stressed as part of a comprehensive vocational education program focused on core trade skills.[46] [47]

Community Colleges.—Henry Ford Community College (Michigan), Eastfield Community College (Dallas), and Glendale Community College (Los Angeles County) were the sites studied. The major functions of their programs are: 1) granting 2-year associate degrees (or degree options) focusing on or including robotics or computer-aided design, and 2) offering short-term work-study training programs jointly operated with industries and government agencies for students with previous college-level technical coursework. Also included among community college functions are career counseling and agreements with local universities to enable students to proceed directly to B.S. programs. The 2-year colleges studied are all characterized by responsiveness to industrial skill needs and coordination with local industries on such matters as curriculum content and equipment needs. Major strengths are the practical orientation of the technical programs, the industrial experience of the instructors (usually a hiring requirement), and their balancing of the needs of the students and the community at large with industrial demands for specific skill preparation. The colleges' focus on practical, technician-level coursework makes them excellent vehicles for responding to the growing need to retrain displaced workers. Major weaknesses stem primarily from lack of adequate funding to purchase industrial-quality equipment and build needed laboratory facilities.[48]

Universities.—The examination of the university's role in PA instruction focused on four engineering and technology programs: 1) University of Michigan; 2) Brigham Young University; 3) Texas A&M University; and 4) Worcester Polytechnic Institute. University approaches range from: 1) introducing PA studies as a major focus (CAD) or minor option (CAM) in 4-year technology programs that substitute practically oriented coursework for the most theoretical of the courses required in engineering curricula; 2) introducing CAM into undergraduate curricula through projects with industry or projects that simulate industrial conditions, plus the use of innovative instructional techniques that enable engineering undergraduate students to begin to focus on CAM at that level; to 3) reserving the focus on computer-aided manufacturing (or, computer-integrated manufacturing) for graduate-level programs so that undergraduates may first master the fundamentals of traditional engineering disciplines. In the three universities studied in depth,* computer-aided design is more comprehensively covered in undergraduate engineering or technology curricula than is computer-aided manufacturing.

The research functions observed at universities, and the capacity to engage in PA research, are equally varied, ranging from industrially oriented applications research to long-term research aimed at areas of potentially high technical or economic impact where success is uncertain. While the latter type of research may fill a need that many industries do not have the luxury to address, the former more effectively fills industry's short-term needs.* As in the cases of the high school and college programs, most university programs are limited in capacity by less-than-adequate funding, equipment, and laboratory facilities.[49]

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[45] Texas Instruments case study, 1983.

[46] Ibid.

[47] Oakland County case study, 1983.

[48] Henry Ford Community College, Texas Instruments, and Glendale CAD/CAM Program case studies, 1983.

*University of Michigan, Brigham Young University, and Worcester Polytechnic Institute, case studies, 1983.

Apprentice and Journeyman Training.—The major function of the union training programs observed—both of which serve industrial electricians—is to build PA training onto a solid core of fundamental trade skills either during the final year of apprenticeship training or in voluntary or company-sponsored journeyman training.[50] Union-sponsored or oriented programs observed differ from university and some college programs in that they are not designed to place technology studies in the context of broad-based humanistic education. However, the union programs concentrate more on the development of a given individual's skills than in-plant training programs generally do (see below). Whereas most in-plant training focuses on task-oriented skills required to perform a specific job, the union programs focus on adding PA-related skills to the complete range of skills required to perform as a journeyman in a specific trade.[51]

In-Plant Industrial Training.—All of the inplant training programs observed[52] provide job-specific classroom-laboratory training focused on the precise applications needs of the plant. A broad range of machine- or system-specific programs were examined along with overall systems orientation training for managers. In-plant programs are both efficient and effective because they are: 1) specifically focused on well-defined applications needs; 2) delivered to students grounded in both plant procedures and core trade skills who can put their new skills into practice immediately and continuously; and 3) more user-oriented than other types of PA training, since the trainers are normally in close contact with system users, programers, and maintenance personnel and usually have current or previous plant experience in those fields. However, the streamlined efficiency of in-plant training limits its range: students normally learn only what they need to know to perform their jobs, and no more. Some in-plant training is also limited by a lack of resources devoted to or available for training.

Vendor Training.—The major function of the instructional programs delivered by producers or vendors of PA equipment and systems is machine- or system-specific training which is usually not application-oriented.* Such programs generally are not designed to do more than give customer trainees a thorough orientation to the equipment itself and the basic skills required to use it; advanced vendor training courses impart greater depth of maintenance skills, and some advanced training focuses on generic applications, such as welding or line-tracking (in robotics) and mechanical design or printed circuit board design (in CAD). Some PA vendors, such as GCA Corp. (semiconductor equipment, remote-handling and large-scale robotic systems), offer several levels of structured courses in key areas such as maintenance. Other vendors, such as Computervision (CAD hardware and CAD and CAM software) and Automatix (robotics and vision systems) will develop, on request and for a fee, customized, advanced courses.[53]

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*See the later section on "Cooperative Industry-Education Programs" for discussion of mutual benefits derived from joint education research projects.

[49] University of Michigan, Brigham Young University, Worcester Polytechnic Institute, and Texas Instruments case studies, 1983.

[50] International Brotherhood of Electrical Workers Programmable Controller Training Program.

[51] International Brotherhood of Electrical Workers case study, 1983.

[52] Texas Instruments; an aircraft manufacturer (asked not to be identified); CADAM Inc.; Cincinnati Milacron; and Westinghouse Defense and Electronics Center.

*The five companies profiled are: 1) Computervision, a vendor of computer-aided design systems (both hardware and software); 2) CADAM Inc., a software-only vendor, most of whose CAD software is sold to purchasers of IBM hardware; 3) Cincinnati Milacron, Inc., a producer of computer-controlled machine tools, robots, and other products; 4) GCA, a producer of specialized automated semiconductor equipment; and 5) Automatix, a vendor of custom-designed robotic and vision systems. With the exception of Cincinnati Milacron (CMI)—which was founded in the 1880's and began producing computer-controlled machinery in the 1960's and 1970's—the vendor firms are relatively young companies. GCA and Computervision were established in the late 1960's; Automatix was created in 1980; and CADAM was incorporated in 1982.

[53] New England Programmable Automation Customer Training case study, 1983.

The expense of vendor training is another limitation.* Specific strengths include: 1) a high level of responsiveness to customers' needs, 2) increasing amounts of attention to developing and utilizing instructional methodologies that attempt to combine flexibility with a systematic approach, and 3) an increasing emphasis on the need for in-plant instructor training, manager training, and executive seminars, all of which stress the systems approach to manufacturing and design. The "systems approach," which takes the entire design and manufacturing process in a given environment into account, is especially important in companies that now have or are in the process of building an integrated CAD and CAM database.

Cooperative Industry-Education Programs.—While all of the educational programs covered in the case study series have involved a degree of participation from other sectors, only five of the programs could be characterized as joint ventures in which government agencies and/or industrial firms have assumed a high degree of involvement in program operation. Those are: 1) the Glendale High School CAD program, 2) the Glendale coordinated funding program, 3) the Eastfield College printed wire board program, 4) WPI's Manufacturing Engineering Applications Center, and 5) the Texas A&M integrated circuit design program.

A number of the cooperative programs examined have the potential to increase the educational and/or research capacity of the academic partners, especially those programs that provide equipment and/or laboratory facilities which the school could not otherwise afford. In addition, such programs can provide the industrial partner with education and research services that industry is not organized to provide (e.g., PA-related training delivered in the context of a broad-based education, and a production-free environment in which to conduct applications research). The majority of the joint programs also give the industrial partner access to faculty and to potential employees (i.e., the participating students) who are either specifically trained in occupations in demand by the company or who have some familiarity with company procedures and requirements through participation in joint research projects.

Needs, Problems, and Trends Common to Industry and Education Programs

Summary

Neither the industrial nor the educational sector alone has fully met all PA training needs identified to date, nor has either solved all of the major problems associated with the delivery of such training. Some of those needs and problems are, in fact, common to both industrial training and the instruction delivered in educational institutions.

Common Needs

Long- and Short-Term Strategies.—While industrial organizations need training strategies that meet both short- and long-term needs to support PA implementation and expansion strategies, educational institutions must plan to meet short-term educational needs as best they can despite the difficulty of obtaining equipment and laboratory facilities. Texas Instruments has recognized both needs and supplements its in-plant training activities with extensive involvement in local elementary, secondary, and postsecondary education programs, plus cooperative arrangements with colleges and universities in Texas and elsewhere.[54] At the same time, educational institutions must engage in long-term forecasting and planning consistent with their own educational and research goals and future industrial needs. The University of Michigan, for example, has a long-range goal of strengthening its independent research and development and engineering programs, while continuing to respond in the short term to changing industrial skills requirements.[55]

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*Vendors and producers in some cases offer volume discounts, group discounts, and/or free training slots with purchase of their equipment. But vendor-provided training, while essential with initial purchase of equipment, becomes too expensive as a continued source of instruction. In the case study sites examined, neither vendors nor producers feel that it is a substitute for users establishing in-house training capacities.

[54] Texas Instruments case study, 1983.

Increased Internal Coordination.—The need for increased coordination between design and production departments in industries that either have developed or plan to develop a common CAD and CAM (or computer-integrated manufacturing) database is paralleled by the need for educational institutions to increase the coordination among departments engaged in interdisciplinary research and/or teaching activities. For example, Brigham Young University is working to establish closer ties between its engineering, technology, and science programs in light of the common effects of programmable automation on these courses of study, as well as the need for an interdisciplinary approach in many courses.

Increased Communication.—Enhanced communications networks are needed not only within individual schools and plants, but also between industry and education; among companies engaged in producing, implementing, or expanding programmable automation; and among schools offering PA studies. In the case of the Glendale, Calif., CAD/CAM Training Program, State-level coordination and sponsorship provided both the impetus and the funding resources necessary to give Glendale College and other colleges (or, in some cases, consortia of colleges) participating in the effort, the opportunity to establish high-technology programs.

The object of the State-level sponsors was to demonstrate the feasibility of coordinating both funding sources and public and private organization efforts to support employment and training projects which would also build the educational capacities of the participating schools. The State-level coordination was also a pilot test of the abilities of State agencies to improve local responses to high-technology education and training needs by pooling and coordinating their resources. On the local level, the success of the Glendale program in meeting its goals was aided by the previously established linkages between the college, the Private Industry Council (PIC), and local business and industry.

In addition, prospective students and workers need to be informed about the specific programs offered in particular schools and the present and future skill requirements of the workplace. There are organizations that gather and compile information on programmable automation and other high-technology curricula which can be used by students or workers planning further education.* What appears to be needed, however, is a national mechanism for tapping the resources of the already existing organizations and gathering information from schools and industries that may not yet be included in the numerous studies and unofficial networking done by existing organizations. As important as gathering information on curricula, training methodologies, research, equipment needs, local problems, and local solutions is a mechanism for publicizing that information to teachers, prospective students, and workers who may not even know of the existence of established information organizations. A well-publicized national communications network would enable students to make informed choices of schools that meet their individual needs. It could also make curricular materials from a variety of sources available to schools and industrial training departments.

Exchange of Expertise Between Education and Industry.—The curriculum-development and teaching expertise of instructors in colleges and universities can be of help to industrial trainers facing the onset of increased in-plant classroom and laboratory training for programmable automation. Similarly, colleges

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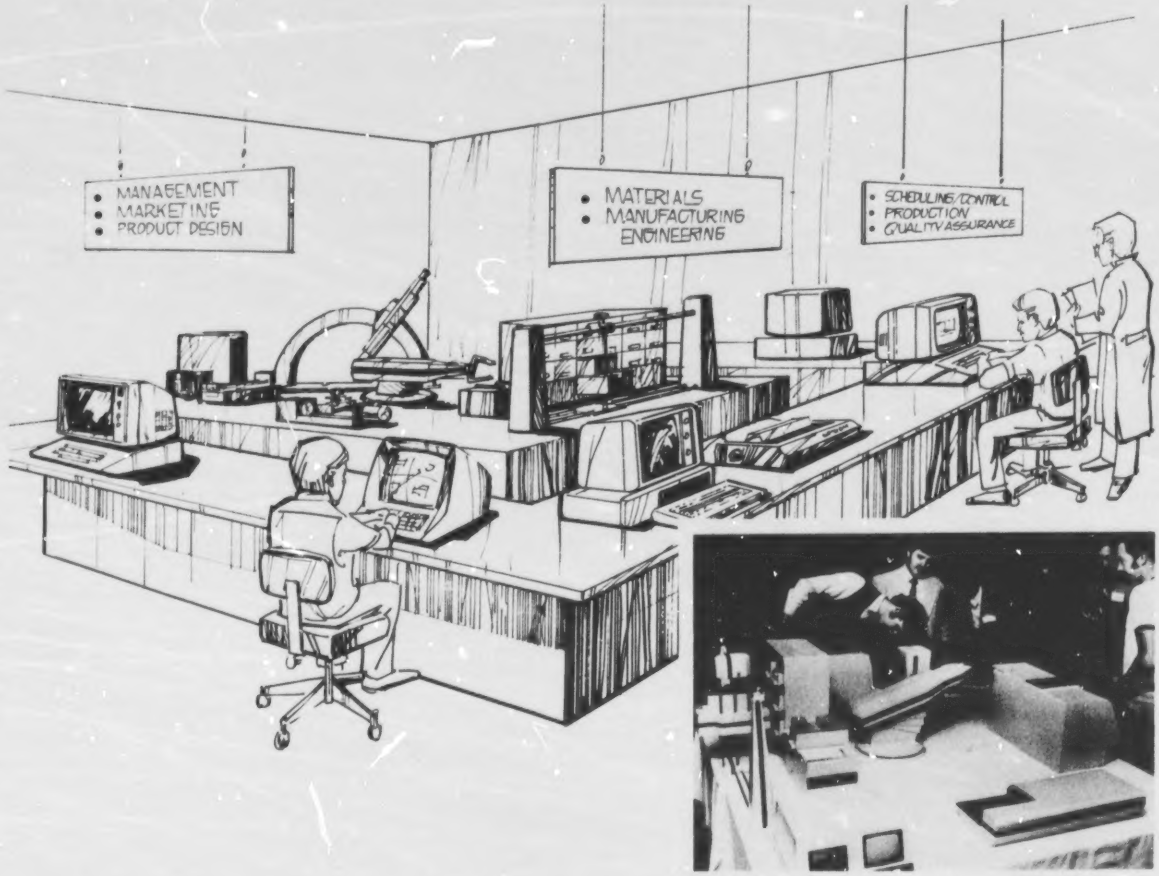
[55] University of Michigan case study, 1983.

*Numerous professional societies—such as the Society for Manufacturing Engineers and Computer-Aided Manufacturing International—enable professional engineers to exchange information on state-of-the-art techniques and problems. In addition, engineering education associations and vocational training societies spread information among educators and trainers. Conferences such as that held by Brigham Young University for universities engaged in PA teaching and research also help. As wide-reaching as these organizations may be, however, they are still limited in that not all trainers and educators can afford the time or receive the funding to attend meetings.



This is a scale model (inset) of the group technology cell that will be a part of BYU's "CAM Mini-Lab." The model was built in the University's Research Laboratory (see caption below)

Brigham Young University's Engineering Technology Department is creating a "CAM Mini-Lab"—a scaled-down version of a highly automated manufacturing facility—for use with students enrolled in "Computer-Integrated Manufacturing" and other courses offered through BYU's Design Technology and Manufacturing Technology degree programs. The "Mini-Lab" is expected to be completely operational in the next 8 months and will be located in the CAM Software Department. Students are building most of the equipment for the lab themselves, including controllers, an automated storage and retrieval device, and a group technology cell that includes a lathe, a mill, and a robot. Once completed, BYU hopes to market the "Mini-Lab" concept to other schools of engineering and technology. For more information on BYU's Engineering Technology Program, see app. A

and universities can benefit from having their students participate in simulated or actual industrial projects.

As one model for such interaction, the specific roles played by company and school representatives in WPI's Manufacturing Engineering Applications Center (MEAC) projects are as follows: Emhart Corp. supplied all the equipment (including the robots themselves and the peripheral equipment needed to develop the applications) and transported it to WPI; covered all major project costs (which, aside from equipment, included administrative costs, equipment maintenance, and a portion of WPI staff salaries); assigned a project manager to be responsible for the overall operation of the various applications projects; and assigned other engineers and factory workers to aid in the research and development. WPI provided laboratory and office space for the resident Emhart staff; a project administrator; students, faculty, and "resident engineers" specially hired to work on the MEAC projects; workshops, demonstrations, and tours for company personnel; and tuition-free coursework for participating engineers who wished to take advantage of the college's educational programs (including work toward M.S. and Ph. D. degrees).

Top-Level Organizational or Institutional Support and Self-Motivated Action by Instructors.—Well-planned and executed training and education requires active support by corporate management or school administrators. The corporate vice president who conceived of and initiated the WPI manufacturing engineering program enlisted top corporate support and acted as an arbitrator between the school and the company and between Emhart corporate and divisional employees when the need arose. Apart from top-level support, the need for individual instructors in educational institutions who take action by developing curricula, making industrial contacts, and keeping themselves abreast of the state of the art is matched by the need in industry for training directors or managers who can convince top management of the need for training to keep pace with PA expansion.

Flexibility.—Both industry and education need the flexibility to incorporate the new training and education needs into traditional practices and procedures. This may, in some instances, require restructuring curricula in educational institutions and restructuring training practices (or instituting new training procedures) in industry. When the need for instruction of production line personnel in the use of programmable equipment arose at the General Motors' "S" Truck Plant, for example, staff in the maintenance department were identified to serve as instructors and a permanent technical training group was formed.[56]

Jointly Sponsored Industry-Education Programs.—Joint programs with industry can significantly increase the capacities of educational institutions to conduct programmable automation education and research programs. While many industries have difficulties freeing equipment or laboratory facilities for student use, others that have been able to do so (e.g., JPL, Singer Librascope, and Emhart,) have seen a return on their investment that takes a variety of forms—ranging from free coursework for company engineers, to assistance in industrial projects, to company-specific training of potential or current employees. Some far-seeing company representatives also recognize that by building the capacities of the schools, they are bettering their future chances of hiring well-educated employees. Some also believe that colleges can potentially save companies training dollars by delivering in-plant training. In most cases, the companies would first have to train the college instructors in their procedures and practices, but industry supporters of contracts with colleges for training maintain that this would be less expensive than company-operated training, and that it has the added advantage of aiding industry and academia at the same time.

Common Problems

Lack of Adequate Resources.—While the lack of adequate funding, equipment, and laboratory facilities for training is most notable in the education sector, this problem has also been observed in some vendor and user firms. A significant implication is that those industries having difficulties filling their own needs for equipment, instructors, and facilities are hardly in a position to aid schools looking to industry for equipment. The national crisis in education that has been receiving increasing attention in the media and in numerous reports appears to be paralleled by the less publicized problem of the low-priority status of training in many industrial organizations. Nevertheless, as the successfully operated industry-education programs illustrate, resources (including equipment and laboratories in industry and the instructional expertise of educators) can be shared; Federal, State, and local government agencies can help to facilitate that sharing of resources by providing additional funds and by creating linkages—as was done on both the State and local levels in the instance of California's coordinated funding Project.[57]

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[56] General Motors case study, 1983.

Resistance to Change.—A number of industry and education representatives have pointed out that many individuals in their own organizations and institutions exhibit a strong resistance to the changes that may be brought about by programmable automation and other emerging technologies. Not only individuals, but entire organizations show this resistance. While over-responding in an ill-considered fashion is certainly a danger, the traditionally gradual change in education and training makes a failure to respond in time a more prevalent—and likely—problem.

Keeping Up With the Constantly Changing State of the Art.—While many educators have difficulty keeping up with industrial advances in technology, and while postsecondary educational institutions as a whole face extreme difficulty in keeping their laboratory equipment up-to-date, industrial trainers (especially in vendor firms) face similar difficulties in keeping up with software updates and new releases of both software and hardware. The solution to this problem, as to so many others, is increased resources allotted to educational institutions and industrial training organizations so that they can hire more trainers, curriculum specialists and, in the case of educational institutions, more faculty to reduce the strain on the departments as a whole. The "solution," however, is a problem in itself, since training resources appear to be scanty in many industrial firms, and funding is a perennial problem in most schools.

Finding and Keeping Instructors.—High school, college, and university instructors who have developed PA expertise are attractive to industry, and must be dedicated teachers to pass up the allure of higher industrial salaries. Many potential instructors never consider professional academic careers for the same reason, leaving the university immediately after completing their studies. Industrial training departments, especially in vendor firms, have similar problems. One potential solution lies in industry contracts with schools for exchanges of expertise, such as those described earlier. This approach can lead to enhancement of the professional competence of instructors.

Common Trends

Cross Training and/or Interdisciplinary Studies Plus the Systems Approach for Engineers and Managers.—Technical colleges and high schools stress the need for interdisciplinary coursework, especially in robotics and other programmable automation studies. This parallels the cross training of mechanics, electronics technicians, and other technician-level workers and maintenance personnel in plants where union provisions do not preclude workers from crossing occupational trade boundaries in the work performed. In some union plants that have such restrictions (e.g., where electrical maintenance personnel do not perform mechanical maintenance functions), inplant training courses often provide familiarity with those portions of the system not directly the responsibility of the individual mechanical or electrical maintenance worker. The systems approach to computer-integrated manufacturing studies offered by some engineering schools is, perhaps, paralleled by inplant training in CAD and CAM networking systems and by systems overview courses for managers.

Technical Management Education and Training.—Overview courses for managers are becoming more common, as are new master's degree programs in technical management for engineering personnel. Some of the universities studied, such as the BYU, combine coursework for a master's degree in business administration with graduate-level engineering or technology courses (often focusing directly on programmable automation) to produce trained technical managers.

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[57] See case study 5: CAD/CAM Operator Training Program, included in app. A to this report.

Increased Attention to the Relationship Between Education-and-Training and Productivity.—This trend is related to the growing emphasis on lifelong learning. A large number of in-plant trainers and managers interviewed equated ongoing in-plant training with increased plant productivity. One of the major selling points of vendor training is that adequate instruction is required to enable workers to make the most productive use of CAD equipment and to keep CAM equipment operating at peak efficiency. Trainers in the union-operated training program studied were, perhaps, the most explicit of all. Said one: "The only thing we have to sell are our skills and knowledge—these must be pertinent if we are to continue to function as productive workers in a changing field."* Educators concerned with the personal productivity of their students after they leave school emphasize the necessity of continuing the learning process after formal education is completed. Programs offered by Worcester Polytechnic Institute, for example, are specifically structured to produce students who are capable of "learning to learn for themselves in a professionally competitive atmosphere." According to one WPI representative, "the net result is that, if the program succeeds in meeting its goals with individual students, those students who become practitioners have an infinite half-life as engineers, instead of the currently predicted 1-year half-life."

Career Guidance and Programmable Automation

Earlier in this chapter it was pointed out that the increasing use of programmable automation in manufacturing environments, along with other forces at work in the economy, is causing individuals and employers to develop new expectations and requirements for services from the U.S. instructional system. One of the expectations shared by individuals and employers alike is that there will be more comprehensive educational and career guidance programs accessible not only to children and young people, but also to adults. As increased use is made of advanced automation in the plant and the office, skills requirements will change and the emphasis on developing a baseline familiarity with advanced technologies—especially the computer—will increase. In turn, the variety of career options and modes of career preparation will change.

Given an era in which lifelong education will be a necessity for most if not all participants in the U.S. work force, there will be an increasing need for educational and career counseling for adults. And in some cases, career counseling for adults may be an alternative to education and training, as has already been demonstrated with some displaced workers who possess marketable skills. To date, there has been no research yielding specific recommendations for altering guidance and counseling programs in accordance with the increased presence of advanced technologies in the American workplace. Yet the potential for increased opportunities in technology-related occupations and the importance of education and career guidance require that a discussion of possible changes to established programs be included in this examination of changing instructional issues.

Educational and Career Counseling in Elementary and Secondary Education

Career guidance for elementary school students more often than not takes the form of structured, periodic classroom sessions devoted to developing an awareness of career choices and options. On the secondary school level, educational experiences designed to increase a student's awareness of possible career choices are usually known as "career exploration programs." School textbook publishers, and individual teachers, have developed materials that may be integrated into established curricula, or that guidance personnel may utilize in special programs designed to stimulate career interests.

As career choices in automated workplace environments increase, preparation for these careers may require that decisions relating to courses of study be made much earlier in a student's initial educational preparation. For example, a preliminary interest in technical or engineering careers may dictate an increased emphasis on a science and math—perhaps even in the elementary grades. In Japanese school systems, science and math education are stressed from the lower elementary grades and onward. In addition, science and math curricula are developed so that one level builds closely on the previous level.[58] It will be important that classroom materials used to stimulate career exploration reflect the likelihood of more frequent changes in careers, as well as the full spectrum of choices available. Given the relatively low participation rates of minorities and women in technical and engineering professions, exposure of minority and female children to career exploration materials will be especially important for future achievement of workplace equality. It will also help ensure that these children can make career decisions based on an examination of all possible choices.

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*A large number of the members of the particular IBEW local studied worked on a temporary or permanent basis for small electrical contractors, many of whom could not afford to provide formal in-house training.

On the secondary level, the goal of career guidance and counseling takes a different form. First, there is more often than not a centralized guidance function in the form of a guidance counselor or, in larger schools, a guidance department. For students who will enter the world of work directly after high school and for students who will go on to college or some other education or training experience, there are five career guidance needs:

- An awareness that career planning is vital . . .
- A broad awareness of alternatives . . .
- Knowledge of a process of decision making . . .
- Recent, easily accessible banks of information . . . and
- Systematic treatment with individualization.[59]

Leaders in the field of career guidance suggest that the work of school counselors will become more important as a result of increased use of advanced technologies in American society and the resulting need to encourage the personal growth required to deal with an increasingly complex and technical world.[60] In addition, information technology will play a greater role in the guidance process itself, as microcomputers, video disks, teletext and videotext serve as vehicles for delivery of career guidance systems to supplement the role of the counselor.[61] A variety of computer-based guidance systems are already used by high school guidance counselors. Many counselors who have used direct search and structured search systems—the two types of career databases currently available—have found them to be valuable resources.[62]

Career Guidance on the Postsecondary Level

Whether an individual enrolls in a degree program or simply takes selected courses, the focus of guidance programs in postsecondary institutions is usually more on placement than on examining career options. This focus has been in keeping with increasing enrollments in specialized, professional education programs. However, as technological and economic change forces individuals and institutions to think more in terms of broad-based occupational preparation rather than specialization, there will be a greater need for career guidance services on the postsecondary level. Barton points out that increases in adult enrollments and the growing need of adults for career counseling, based in part on technological and economic change, will present new challenges to the educational community:

> While there is increasing interest in adults among members of the counseling and guidance profession, that profession has mostly dealt with the young. There is quite a differ-

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[58] National Science Board Commission on Precollege Education in Mathematics, Science and Technology, *Educating Americans for the 21st Century* (Washington, D.C.: National Science Board, September 1983).

[59] JoAnn Harris-Bowlsbey, "A Historical Perspective," *Microcomputers and the School Counselor* (Alexandria, Va.: American School Counselor Association, 1983).

[60] Cynthia Johnson, "The Future," *Microcomputers and the School Counselor (Alexandria, Va.: American School Counselors Association)*, 1983.

[61] JoAnn Harris-Bowlsbey, op. cit., 1983.

[62] Laurence Shatkin, "The Electronic Counselor," *Electronic Learning*, September 1983, pp. 75-77.

> ent set of issues involved in the problem of providing educational advisement and information to adults than there is in facilitating the movement of youth from high school to college. The colleges and universities have had almost a single source from which to get their students—the secondary school. Information about admissions and courses was funneled to students through high school counselors who were the linchpins between the high school and the college. And a standardized test, the Scholastic Aptitude Test (SAT)—at least from the college's standpoint—helped to grade and sort prospective students.
>
> . . . Potential adult students are not gathered in any central place. . . . They often have very specific objectives, and need to know what kind of education will enable them to reach these objectives, and where that education can be found in the community and at least cost in money and time. People who give good educational advice to adults have to know about the constraints working adults encounter. They must be briefed about employment and avenues of advancement, about what employers require, in order to relate an educational plan to an employment outcome.[63]

Other Sources of Career Counseling for Adults

A variety of organizations and institutions within the community now provide career counseling services to adults who are participants in the work force or who wish to enter or reenter the work force. In 1980, there were an estimated 7,991 commercial employment establishments operating in the United States. Some of them specialize in particular fields such as data processing or engineering, while others work with individuals interested in a broad range of career pursuits.[64]

Nonprofit organizations, such as community-based groups and churches, are becoming increasingly active, particularly in periods of high unemployment. National nonprofit organizations also have been formed to assist individuals in identifying job opportunities. For example, the National Center for Urban and Ethnic Affairs recently formed a national information clearinghouse for use by community groups across the country for self-help job counseling programs to aid the unemployed. The Center's clearinghouse staff now offer workshops to community leaders interested in establishing self-help job counseling centers.[65]

Other national nonprofit organizations are examining career opportunities for particular groups within the population. For example, Wider Opportunities for Women, Inc. (WOW), a Washington, D.C.-based organization that focuses on developing nontraditional career opportunities for women, is now sponsoring a Women's Work Force Project, to identify potential opportunities for women in high-technology industries.[66]

The Corporation for Technological Training, a nonprofit organization serving high-technology employers and individual job seekers in Montgomery County, Md., has created a Technical Occupations Employment Group that assesses industry skill requirements and provides testing, counseling, retraining, and placement assistance on an as-needed basis. Given the potential variances in skill mixes among high-technology and technology-intensive industries in different regions, such programs that focus on the needs of particular geographic areas or target populations may increase in numbers in the near-term future, provided there are available resources for their establishment and strong industry support.

As the need for educational counseling and career guidance increases because of expanded use of PA in manufacturing, advanced technologies in other types of work environments, and other factors, the need increases for current, reliable information on occupational trends and occupational preparation. This need for more efficient means of organizing and updating occupational information suggests the need for greater use of microcomputers and other technologies in the counseling process.[67]

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[63] Paul Barton, *Worklife Transitions* (Washington, D.C.: National Institute for Work and Learning, 1982).

[64] Data provided by the U.S. Department of Commerce.

[65] *NCUEA Building Blocks,* winter 1983.

[66] *Bridging the Skills Gap: Women and Jobs in a High Tech World* (Washington, D.C.: Wider Opportunities for Women, 1983).

Job Counseling, Outplacement, and Retraining for Displaced Workers

Many semiskilled and skilled workers who have lost their jobs in automobile, steel, and other heavy manufacturing industries, or who are on indefinite lay-off with slim prospects for ever returning to their former jobs, are looking for new jobs within the manufacturing or the service sector. In addition, due to both the increasing use of programmable automation and economic changes, the jobs of many currently employed semiskilled and skilled workers are at risk.

Unless these individuals are willing to take lower paying, lower skilled jobs, many will need to be retrained or to enhance their present skill levels so that they can compete for available skilled jobs. A few companies, unions, State universities, and community colleges now offer instructional programs designed with displaced workers in mind. A few universities and community colleges have begun to offer free courses to the unemployed in order to assist them in upgrading their skills.[68] However, other instructional programs are a "force fit." Existing curricula and instructional methods may be inappropriate for the skill levels of displaced workers or for use with older adults. Often, too, skill levels of enrollees are not assessed initially, nor is placement of enrollees after completion of training guaranteed.[69] As a result, participation rates are often low.

In the past, few retraining efforts for displaced workers have been sponsored by industry, for a variety of reasons, including: the lack of local alternative career opportunities, for which instruction could be provided; workers who resisted retraining in hopes that they would be called back to their old jobs; and the inability of companies closing plants to afford the cost of retraining displaced workers.[70] To date, most of the retraining programs established have been paid for with Federal funds. For example, the Trade Adjustment Assistance Program was the key funding source for the relocation programs of the 1970's. Special retraining projects for individuals affected by massive layoffs were funded through Department of Labor discretionary grants.[71] In recent years, State and local governments, through their economic development agencies, have begun to establish State training systems and skills centers. These centers aim to attract new industries to their geographic areas by providing them with a pretrained work force. They are often sources of training for displaced workers who meet entry eligibility requirements.[72]

The following factors complicate the process of providing retraining for displaced workers: 1) many have been out of school for a number of years and are uncomfortable with classrooms and instructional approaches designed for use with younger and less experienced students; 2) many have families and feel they cannot participate in education and training programs unless they also receive some form of stipend for living expenses or payment for work performed while engaged in on-the-job training; and 3) many need specialized job counseling and placement assistance in order to determine how best to utilize their present skills in preparing for new careers and in seeking out new employment opportunities.

Retraining programs established with the special needs of displaced workers in mind—programs in which their current skills and knowledge base are taken into account—are critical if the United States is to minimize the problems of worker dislocation and increased use of PA on the manufacturing work force. Often, pretraining programs are required to address basic skills deficiencies or to reinforce basic skills, such as math, or to reinforce skills that have not been utilized in the jobs previously held by these workers.

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[67] Harris-Bowlsbey, op. cit., 1983.

[68] "Free Courses Offer Jobless a 2d Chance," *New York Times*, June 28, 1983.

[69] For a detailed account of one such program see "Retraining '83?" *Washington Post*, Nov. 6, 7, 8, and 9, 1983. The series describes a technician training program for former production line workers at General Motors' Southgate Plant in southern California.

[70] Jeanne P. Gordus, Paul Jarley, and Louis Ferman, *Plant Closings and Economic Dislocation* (Kalamazoo, Mich.: W.E. Upjohn Institute for Employment Research, 1981).

[71] *Worker Adjustment to Plant Shutdowns and Mass Layoffs: An Analysis of Program Experience and Policy Options* (Washington, D.C.: National Alliance of Business, March 1983).

[72] Ibid.

Whether or not retraining is required for continued participation in the work force, the two types of services that most displaced workers need are job counseling or outplacement and retraining. These are discussed in more detail below.

Job Counseling/Outplacement

There are many similarities between the needs of displaced salaried workers for job counseling and placement assistance and the needs of displaced hourly production line workers. Both groups require assistance in assessing their marketable skills and in identifying job opportunities in which their skills may be utilized. If new skills need to be developed, both salaried and hourly workers need assistance in identifying appropriate sources of training and retraining. However, there is a marked difference in the ability of hourly workers to " . . . articulate value rather than need in representing themselves to prospective employers."[73] For example, in responding to the question, "Why should I hire you?" the answer given by the former hourly employee will often be, "Because I need it to support my family," rather than "Because I have the following skills." Organizations that have provided job counseling services to production line workers have noted that former hourly employees are frequently unable to project a positive image of themselves and tend to think of themselves only in terms of their previous jobs. Tom Jackson, whose consulting firm has worked with hourly employees displaced from the transportation, metalworking, electronics, petrochemical, and retail sales industries, describes the primary goal of job counseling and outplacement for these workers in this way:

> The fundamental issue here is to go beyond job title to the individual and the skills he or she possesses, as well as the qualities. Our job is to help the individual to reestablish his/her fundamental versatility and, through it, to adapt to change. The qualities that are unique to an individual are the forces that embody that person's ability to develop new skills. This is what we so often miss when we just look at the job a person has performed, rather than looking at the total person. Unfortunately, our educational institutions and many employers reinforce this limited view of the individual.[74]

Job Clubs and Seminars.—One of the most successful forms of job counseling and outplacement for former production line workers has been the job club, an organized group of unemployed workers who meet frequently to discuss and reinforce each other's job seeking

Raymond O. was employed for 17 years as a Research Assistant with the Jones & Laughlin Steel Corp. in Pittsburgh, Pa. When he lost his job, he enrolled in the Robotics Installation and Repair Program developed especially for displaced steel workers by the Community College of Allegheny County, in close cooperation with the Westinghouse Corp., a producer of robotics equipment. Now Mr. O. attends classes 5 nights a week and works for a contractor during the day installing robots efforts. Job clubs are usually limited to 25 people or less. Sessions are devoted to job counseling and obtaining job leads, often with the help of professional counselors, and to practicing interviews. The other common type of job counseling for former hourly production personnel is job search seminars delivered by trained consultants.[75] Goodyear Tire & Rubber Co., in conjunction with plant closings in Conshohocken, Pa., and Los Angeles in 1980, was the first U.S. firm to provide job counseling and outplacement to hourly production line workers, in addition to salaried administrative and supervisory personnel.[76] Six case studies of plant closings prepared for use in conjunction with a 2-day conference on plant closings sponsored by the Department of Labor in 1981 all stressed the importance of getting displaced workers actively involved in readjustment processes, including counseling and motivation sessions.[77]

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[73] Interview with Tom Jackson, chairman, The Career Development Team, Inc., March 1983.

[74] Interview with Tom Jackson, op. cit., March 1983.

Other Sources of Counseling and Placement Assistance.—The U.S. Employment Service, established under the Wagner-Peyser Act of 1933, has over 2,800 offices across the Nation. While the Employment Service offers all unemployed persons access to job listings and assistance in matching their skills to available job opportunities, the counseling and placement services it provides are extremely limited in scope. This is due partly to redefinitions over the years by the U.S. Department of Labor of the primary clientele for the Employment Service. For example, in 1965, the emphasis of the Employment Service was to be on working with the "employable"—individuals who already possessed fairly marketable job skills, but who needed access to listings of available jobs. By 1971, however, the focus of Employment Service efforts was changed to working with those who were viewed by employers as "least employable"—individuals lacking basic math, reading, and language skills, and possessing physical or personal characteristics perceived as barriers to employability. With this shift in focus, most of the counseling provided by Employment Service personnel was received by those who were least "job-ready," or who had mental or emotional problems.[78]

Given the changes in the designated audience for the Employment Service over the years since its creation, it is difficult to estimate how useful a tool it has been to displaced workers. Under the Trade Act of 1974, legislation designed to provide adjustment and relocation assistance to workers displaced as a direct result of foreign competition, the Employment Service is designated to administer employment services for the Trade Readjustment Assistance Program (TRA). For fiscal year 1981, the Department of Labor reported that of the 79,000 workers registered with the Employment Service under TRA, only 7,000 were placed in jobs as a result of Employment Service assistance.[79]

The Employment Service (called the Job Service in some States) has been designated to provide counseling and placement assistance to displaced workers under Title III of the newly enacted Job Training Partnership Act (JTPA). However, employers have been reticent over the years to list available job openings with the Employment Service/Job Service, partly because of the perception that, since its establishment, the agency has handled predominantly jobs with the lowest pay and the highest turnover.[80] These conditions, unless corrected, may influence how effective a role the Job Service can play in counseling and assisting displaced workers eligible for assistance under JTPA.[81]

CETA and Job Counseling/Outplacement.—Displaced workers were among the target groups eligible for assistance under Title II-C of the Comprehensive Employment and

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[75] National Alliance of Business, op. cit., 1983.

[76] Tom Jackson, "Industrial Outplacement at Goodyear-Part 2: the Consultant's Viewpoint," *The Personnel Administrator*, March 1980, pp. 45-48.

[77] *Plant Closings: What Can Be Learned From Best Practice* (Washington, D.C.: U.S. Department of Labor, 1982).

[78] Barton, op. cit., 1982.

[79] *Employment and Training Report of the President*, 1983.

[80] Barton, op. cit., 1982; testimony: U.S. Chamber of Commerce; National Alliance of Business, Committee for Economic Development in hearings before the Joint Economic Committee, Sept. 16, 23, 26, 1983.

[81] National Alliance of Business, March 1983.

Training Act (CETA). Under this section of the act, workers displaced through mass layoffs or plant closings were eligible for retraining, but only if they had received official notice of layoff within 6 months of their day of application and if the local CETA prime sponsor could certify that there was little or no opportunity for these workers to find employment in the same or an equivalent occupation within that geographic area. Given the complexity of the eligibility requirements, and also the 6.5-percent limit on retraining for those who did not meet standard income eligibility requirements, the infrequency of advance notice of plant closings, and the overall mission of CETA to serve the economically disadvantaged, few CETA prime sponsors used Title II-C moneys to retrain displaced workers.[82] In addition, while the intent of the CETA legislation was for counseling and placement assistance to be provided by local CETA offices or designated contractors, pressures on local CETA personnel to "train and place" resulted in little time for bona fide counseling and placement assistance.[83]

In summary, from available evidence, it appears that job search counseling and placement assistance have been effective tools in assisting displaced workers in improving their morale and self-image, and in developing adequate job search skills. The most effective sources of job counseling and outplacement services utilized to date with displaced workers have been job clubs and job search seminars delivered by trained consultants. However, in most instances, these services were delivered at the discretion of individual employers and have not been made widely available.

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[82] Ibid.

[83] Barton, op. cit., 1982.

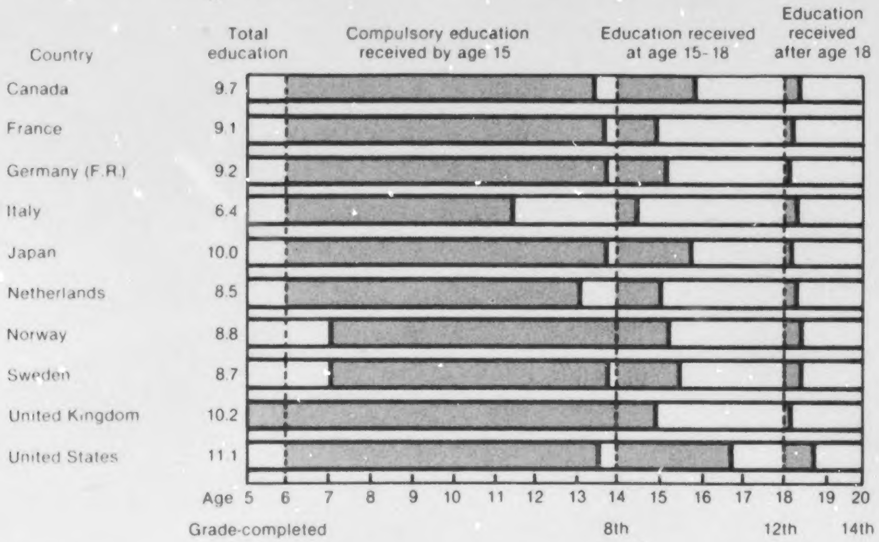
Education and Training in Europe and Japan

An education system in any country is a reflection of the values and traditions of the society it serves. As such, it is difficult to compare and contrast one national instructional system with another without making allowances for cultural and economic differences. Other distinctions in education systems, such as the ratio of public to private institutions, further complicate the process. Over the past year, a number of national studies have been critical of the U.S. education system and have identified attributes of instructional programs in Japan and Europe to be considered for adoption in this country. This section of the chapter will examine some of the similarities and differences between the United States, Europe, and Japan in approaches taken to instruction that serves as a foundation for PA-related skills development or that develops skills required in automated manufacturing.

Summary of Comparative Data

In the mid-1970's, the National Center for Education Statistics (NCES) reviewed and summarized findings from several studies that compared education in the United States with that of nine other countries: Canada, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, and the United Kingdom. NCES found that for the age group 25 to 64, the United States ranked first in adult educational attainment, with an average of 11.1 years of formal instruction. The United Kingdom was next highest, at 10.2 years of formal schooling, but closely followed by Japan, at 10.0 years (see fig. 21). By 1976, in all countries except Canada and the Netherlands, adult males aged 15 and over had slightly higher rates of educational attainment than females in the same age group. However, by 1980-81, the

Figure 21.—Comparison of Years of Formal Instruction Completed by Adults



SOURCE: National Center for Education Statistics, 1976.

numbers of 18-year-old men and women in the Community of Ten* countries who were full-time students had increased by 36 percent for each sex.[84] NCES found education was a major government expenditure in all the nations examined, but Canadian expenditures represented the highest percentage of GNP (6.5), closely followed by the Netherlands (6.3 percent). U.S. expenditures in the year examined (1973) represented only 5.1 percent of GNP, while in Japan (for 1971), education-related expenditures amounted to only 3.0 percent of GNP (see fig. 22). During the the period 1960-70, the United States had less growth in higher education enrollments not attributable to population growth than any of the other countries studied. Immediately prior to the period examined, the United States had greater rates of higher education enrollment growth than any of the other nations (see table 54).

Vocational Training.—A 1982 comparative study of vocational training systems in the Federal Republic of Germany, Austria, Korea, Taiwan, Spain, Holland, Japan, Liechtenstein, Great Britain, Ireland, Portugal, Switzerland, and the United States, found that vocational education is not highly regarded in these countries relative to its importance in producing skilled labor for continued industrial development. The vocational programs of the countries examined varied considerably in scope, enrollment levels, and available resources. For the most part, countries with long-established vocational training tended to consider apprenticeship as a broad-based foundation for lifelong, skills improvement. In contrast, nations that required rapid skills development in order to meet the needs of accelerated rates of industrial growth seemed to favor shorter term, specialized instruction delivered by vocational training schools or by industry personnel at manufacturing sites.[85]

An important measure of the quality of initial vocational preparation (secondary level) is

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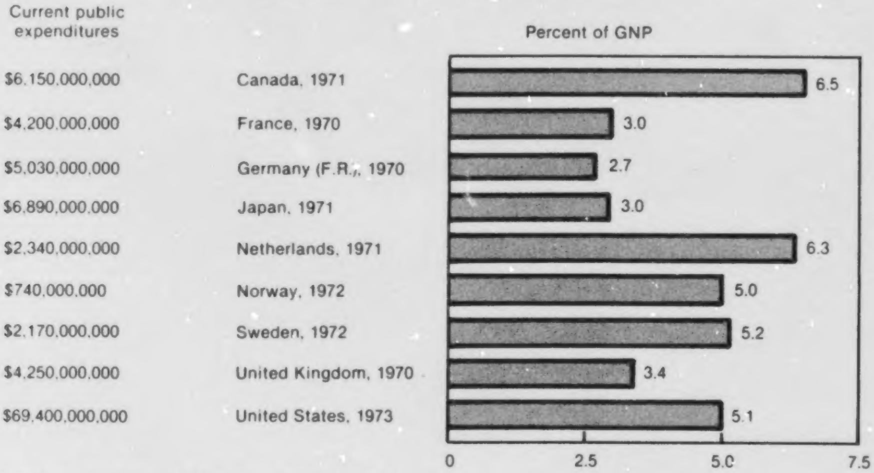
*Federal Republic of Germany, France, Italy, The Netherlands, Belgium, Luxembourg, United Kingdom, Ireland, Denmark, and Sweden.

[84] "Education and Training," *Eurostat Statistical Bulletin*, Oct. 28, 1982.

[85] *Comparison Among the Different Vocational Training Systems in the Countries Participating in the I.B.W.*, International Organization for the Promotion of Vocational Training and the International Competitions of Vocational Training for Young People, July 1982.

Figure 22.—Comparison of Public Expenditures for Education



SOURCE: National Center for Education Statistics, 1976.

Table 54.—Growth of Full-time Enrollment in Education, by Level in Selected Countries, 1960-70

	Annual average compound growth rate					
	In school-age population		In enrollment		In enrollment not attributable to population change	
Country	Secondary	Higher	Secondary	Higher	Secondary	Higher
Canada	3.3	4.4	6.0	11.3	2.6	6.6
France	1.3	4.1	3.8	11.2	2.5	7.1
Germany (F.R.)	1.4	−2.1	3.3	7.3	1.9	9.6
Italy	−0.2	0.1	5.7	9.5	6.0	9.4
Japan	−1.3	2.0	−0.2	9.0	1.1	6.9
Netherlands	0.4	3.4	2.8	7.8	2.4	4.3
Norway	0.9	4.2	NA	9.4[a]	NA	4.7
Sweden	−1.3	3.4	3.5	NA	4.9	NA
United Kingdom	−0.1	2.4	1.2[a]	10.0[a]	1.3[a]	7.4[a]
United States[b]	2.8	4.1	3.1	8.3	0.3	4.0

[a] Estimated.
[b] 1959-70.

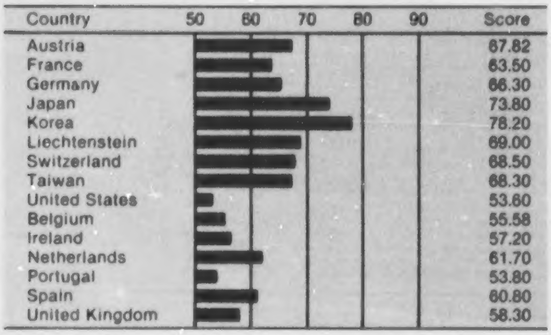
SOURCE: Organization for Economic Cooperation and Development, Paris, France, *Educational Statistics Yearbook*, 1975, vol. 1, sec. II.

the ability of those who have participated to demonstrate the mastery of skills. The International Skill Olympics, sponsored by the International Organization for the Promotion of Vocational Training, are designed to provide young people representing 14 member nations with opportunities to gain recognition for excellence in the skilled trades.

The United States has participated in six international competitions since 1973. As illustrated in figure 23, the United States has had the lowest average level of performance over the first five competitions, with a score as much as 24 points behind Korea and Japan and as much as 15 points behind Switzerland, Austria, Germany, and France. Although the

Figure 23.—Results of the International Skills Olympics

Average level of performance of national competitors in international competition since 1975

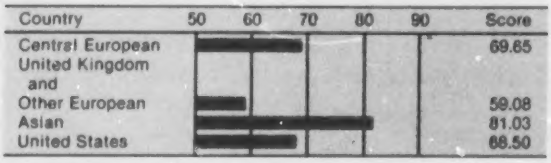


SOURCE: Harold Lewis, *Report on Participation in the International Skills Olympics* (Vocational Industrial Clubs of America, 1983).

United States ranked first in the auto mechanics competitions and third in the demonstration of electronics skills (see fig. 24), it held last place in the precision machining, welding, and construction trades. In assessing U. S. performance, an official of the Vocational Industrial Clubs of America, Inc. (VICA) has noted that the countries who placed highest in the International Skills Olympics include our toughest industrial competitors. VICA attributes the state of preapprenticeship trades skills in the United States, at least in part, to ". . . an adversarial relationship that has developed between government, industry, labor and education regarding the production of a highly skilled, basic trades work force."[86]

Figure 24.—Results of the International Skills Olympics

Electronics



SOURCE: Harold Lewis, *Report on Participation in the International Skills Olympics* (VICA, 1983).

Features of the Japanese Education and Training System With Relevance for Programmable Automation

This section highlights aspects of education and training systems in Japan that lay the groundwork for or develop skills directly related to programmable automation.

The Japanese education system is known throughout the world for its rigorous curriculum—particularly on the elementary and secondary levels. In a recent book on Japanese high schools, Thomas P. Rholen of the Center for Japanese Studies, University of California, estimated that as a result of an accelerated elementary and secondary curricula, ". . . the average Japanese high school student has the equivalent basic knowledge of the average American college graduate." One in ten Japanese students do not finish high school, compared with one in four Americans.[87]

The Japanese education system was reformed after World War II. During this period, many new high schools, colleges, and universities were established and education through the junior high school level became mandatory for all citizens. This change in the mandatory education requirement and the broadening of access to instruction was a major contributor to Japanese industrialization.[88] Emphasis on science and math education begins in the early elementary grades. Three hours each week of math instruction in first grade is gradually increased to 6 hours each week in grades 4 through 6. Science education is provided by elementary school teachers who did not specialize in science but who have attended in-service training programs in government-established science education centers. While the goal of science education in elementary schools is to create a positive attitude toward science, curriculum is more structured on the junior and senior high levels. The Japanese Ministry of Education, under authority of the Science Education Promotion Law of 1953, has established a program to improve elementary and secondary school science education—a program that includes grants to individual schools for the purchase of science equipment.[89]

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[86] Harold Lewis, *Report on Participation in the International Skill Olympics*, presented at the American Vocational Association Annual Conference, December 1983.

[87] Thomas P. Rholen, *Japan's High Schools* (University of California Press, 1983).

[88] Y. Oshima, "Recent Trends of Manufacturing Technology in Japan," *Automatica*, vol. 17, No. 3, May 1981, pp. 421-440.

Japanese students who go on to high school enter one of a number of programs: general, engineering, agriculture, or commerce.[90] Examinations are required for high school entrance and the scores received on these exams determine each individual's occupational and social status. Vocational schools are available to students who do not achieve high ranking on high school entrance exams. The entire high school curriculum is geared to preparing students for highly competitive, college and university entrance examinations.[91]

Shortages of technical and engineering instructors on the junior college, college and university levels have resulted in few robotics course offerings in Japan. In addition, some universities do not consider robotics an appropriate topic for inclusion in engineering curricula. As a result, engineering graduates often require additional instruction before they are prepared to work in automated manufacturing facilities. However, some educational institutions that are not under the jurisdiction of the Japanese Ministry of Education are beginning to offer robotics programs in response to the needs of Japanese industry.[92]

Japanese manufacturers now operate a few engineering schools of their own. These institutions offer programs in robotics operation and maintenance, as well as industrial engineering programs that include robotics instruction.[93] In Japan, industry assumes responsibility for training and retraining its employees. Within firms where "lifetime employment" is the official policy, industry-provided instruction is a necessity, since the majority of new employees recruited have just completed their formal education.[94] The amount and type of training and retraining received by an individual is highly dependent on the stage of the worker's career and, to a lesser extent, on expected tenure. Training for entry-level and young workers is more extensive and formal than instruction for older employees, although experienced workers automatically receive formal training upon promotion.[95]

A study conducted by the Japanese Ministry of Labor on the impact on employment of robotics and NC equipment in 10,000 Japanese manufacturing facilities found that over 60 percent of the companies had initiated specialized training programs in conjunction with adoption of these technologies.[96] However, shortages of technical instructors are an impediment to the establishment of PA-related training in many Japanese firms, just as they are for U.S. companies. Producers of PA equipment and systems provide some training, but there is no information available on its nature or content. As is the case in the United States, small manufacturing firms do not have the time or the resources to provide PA-related instruction to employees.[97]

Training Offered by a Japanese Firm in the United States.—Training programs offered by Nissan Motor Manufacturing Corp. U.S.A. are representative of employee education and training provided by the Nissan Corp. in Japan. Nissan U.S.A.'s truck manufacturing facility in Smyrna, Tenn., is one of the most automated of Nissan's plants, with 219 robots and other forms of automated equipment and systems in use in body assembly, stamping, and painting operations; and a "just-in-time" parts delivery system.

The training system adopted at Nissan U.S.A. is one manifestation of the distinctive approach being taken to plant management. In keeping with a streamlined, five-level management structure, an interest in encouraging employee participation in plant decisionmaking and the need to move employees to different stations in the facility to improve productivity, Nissan U.S.A. has developed special maintenance technician, manufacturing technician, and supervisor training programs for its personnel. Technician training is designed to develop multiple skills and produce an employee who can perform a number of different jobs and work effectively as a member of a team. Instructors are Nissan personnel, professors from nearby universities, or training consultants. Some of the supervisory personnel were sent to Japan for instruction lasting from 1 to 4 months that took place in selected Nissan plants prior to the opening of the Smyrna facility in 1983. Production line personnel who are not technicians or supervisors receive a minimum of 21 hours of general instruction, then as much as 20 hours of job-specific training, such as body assembly.*

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[89] *U.S. Science and Engineering Education and Manpower: Background; Supply and Demand; and Comparison With Japan, the Soviet Union and West Germany*, report prepared by the Congressional Research Service for the Subcommittee on Science, Research and Technology, House Committee on Science and Technology, April 1983.

[90] Souji Inagaki, *Education and Training: Comment From Japan*, paper presented at the 13th ISIR/Robot 7.

[91] Rholen, op. cit., 1983.

[92] Inagaki, op. cit., 1983.

[93] Inagaki, op. cit., 1983.

[94] Paul H. Aron, *The Robot Scene in Japan: An Update* (New York: Daiwa Securities America, Inc., Sept. 7, 1983).

[95] James A. Orr, et al., *U.S.-Japan Comparative Study of Employment Adjustment* (Washington, D.C.: U.S. Department of Labor-Japan Ministry of Labor, November 1982).

[96] Aron, op. cit., 1983.

[97] Inagaki, op. cit., 1983.

Nissan U.S.A. has opened a 30,000 square foot, onsite training facility that contains classrooms and a shop area that has demonstration models of all robots in use in the plant, a paint booth and a maintenance area.[98] Figures 25, 26, and 27 illustrate the training processes for these training programs, from employee selection for preemployment training through certification. Instruction offered at the Smyrna plant may be a reflection of the more extensive use of programmable automation by Japanese firms to date, or it may simply be a reflection of a different approach to training for production line personnel than that taken by American companies.

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*Note that the Japanese use the term "technician" relatively broadly, applying it to individuals designated production workers by Americans.

[98] "Nissan Trains U.S. Workers in Japan," *Automotive News*, May 31, 1982; address by Marvin T. Runyon, President and Chief Executive Officer, Nissan Motor Manufacturing Corp. U.S.A. before the Foreign Correspondents Club of Japan, Tokyo, Japan, Mar. 29, 1983; material provided by Larry P. Seltz, Director, Personnel Development, Nissan U.S.A.; "Stringent Screening, Training by Nissan," *American Metal Market Metalworking News*, June 6, 1983.

Assessment: Capacity of the U.S. Instructional System to Meet the Challenge Posed by Programmable Automation

Current Instructional Capacity

There is little information on the number of educational institutions with course offerings or full-blown curricula for programmable automation, with the exception of robotics and computer graphics. Robotics International, an affiliate group of the Society for Manufacturing Engineers, conducted a survey of over 2,000 trade and technical schools, community colleges, and universities to identify robotics training and education activities in North America. Findings indicated that, in the summer of 1982, there were 27 institutions that listed robotics degrees or options among their programs and 74 more that offered robotics courses.[99] Table 55 is a listing of the responding institutions categorized by type of program and, within types, by kind of institution. The amount of educational activity related to robotics probably reflects the large amount of attention this form of PA has received over the past few years more than it does the degree of sophistication currently found in robotics curricula.

Computer Graphics World, a monthly, commercial journal that tracks advances in computer graphics software and applications, con-

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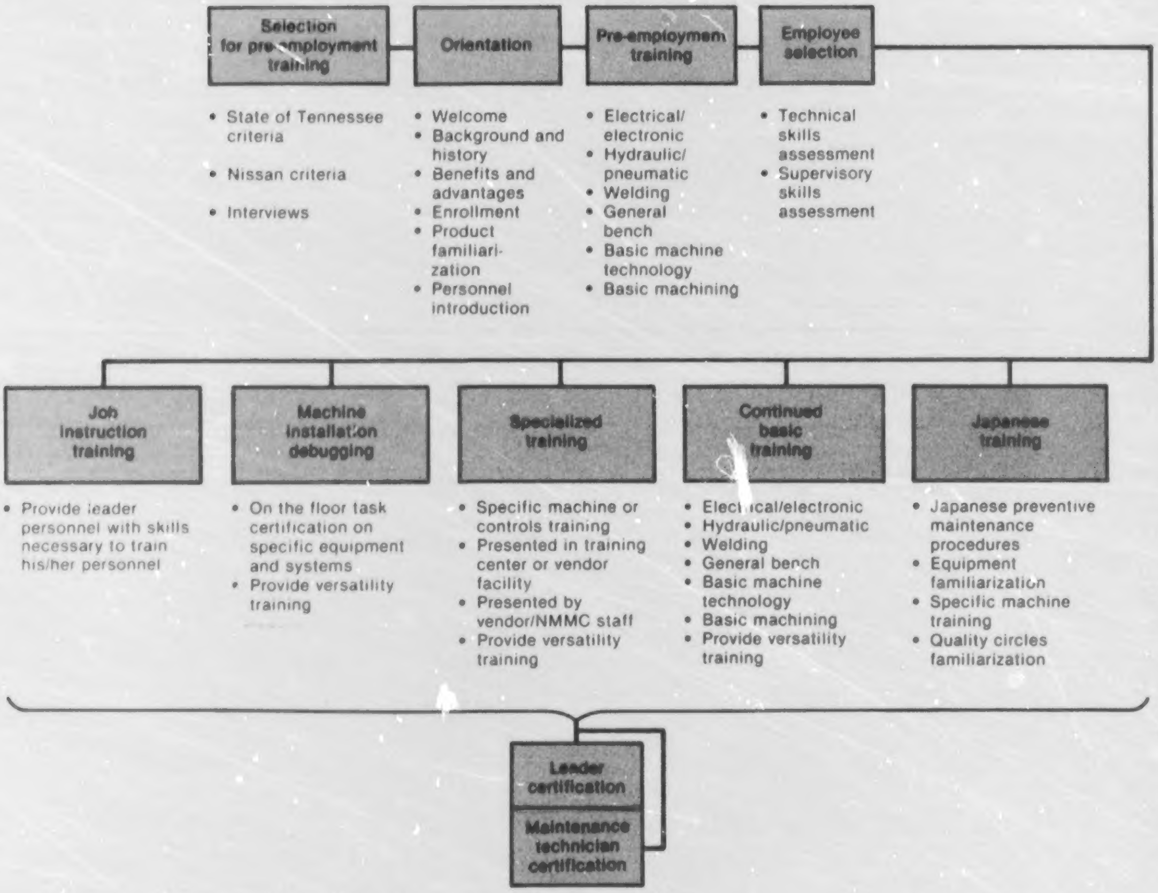
[99] *Directory of North American Robotics Education and Training Institutions*, Robotics International, 1983.

Figure 25.—Maintenance Technician Training at Nissan U.S.A.


Selection for pre-employment training
Orientation
Pre-employment training
Employee selection
• State of Tennessee criteria
• Nissan criteria
• Interviews
• Welcome
• Background and history
• Benefits and advantages
• Enrollment
• Product familiarization
• Personnel introduction
• Electrical/electronic
• Hydraulic/pneumatic
• Welding
• General bench
• Basic machine technology
• Basic machining
• Technical skills assessment
• Supervisory skills assessment
Job instruction training
Machine installation debugging
Specialized training
Continued basic training
Japanese training
• Provide leader personnel with skills necessary to train his/her personnel
• On the floor task certification on specific equipment and systems
• Provide versatility training
• Specific machine or controls training
• Presented in training center or vendor facility
• Presented by vendor/NMMC staff
• Provide versatility training
• Electrical/electronic
• Hydraulic/pneumatic
• Welding
• General bench
• Basic machine technology
• Basic machining
• Provide versatility training
• Japanese preventive maintenance procedures
• Equipment familiarization
• Specific machine training
• Quality circles familiarization
Leader certification
Maintenance technician certification

SOURCE: Nissan Motor Manufacturing Corporation U.S.A.

ducted a survey in 1983 designed to identify universities that offer the following types of computer graphics instruction:

- computer graphics research,
- animation,
- CAD and CAM,
- computer-aided instruction,
- design/architecture,
- design/graphic arts,
- land resource,
- medicine, and
- other.

Results of the survey indicate that 84 universities in the United States and five universities in Canada provide one or more types of computer graphics instruction in their engineering, drafting, computer science, or art programs. However, the survey did not evaluate the relative quality of these programs.[100]

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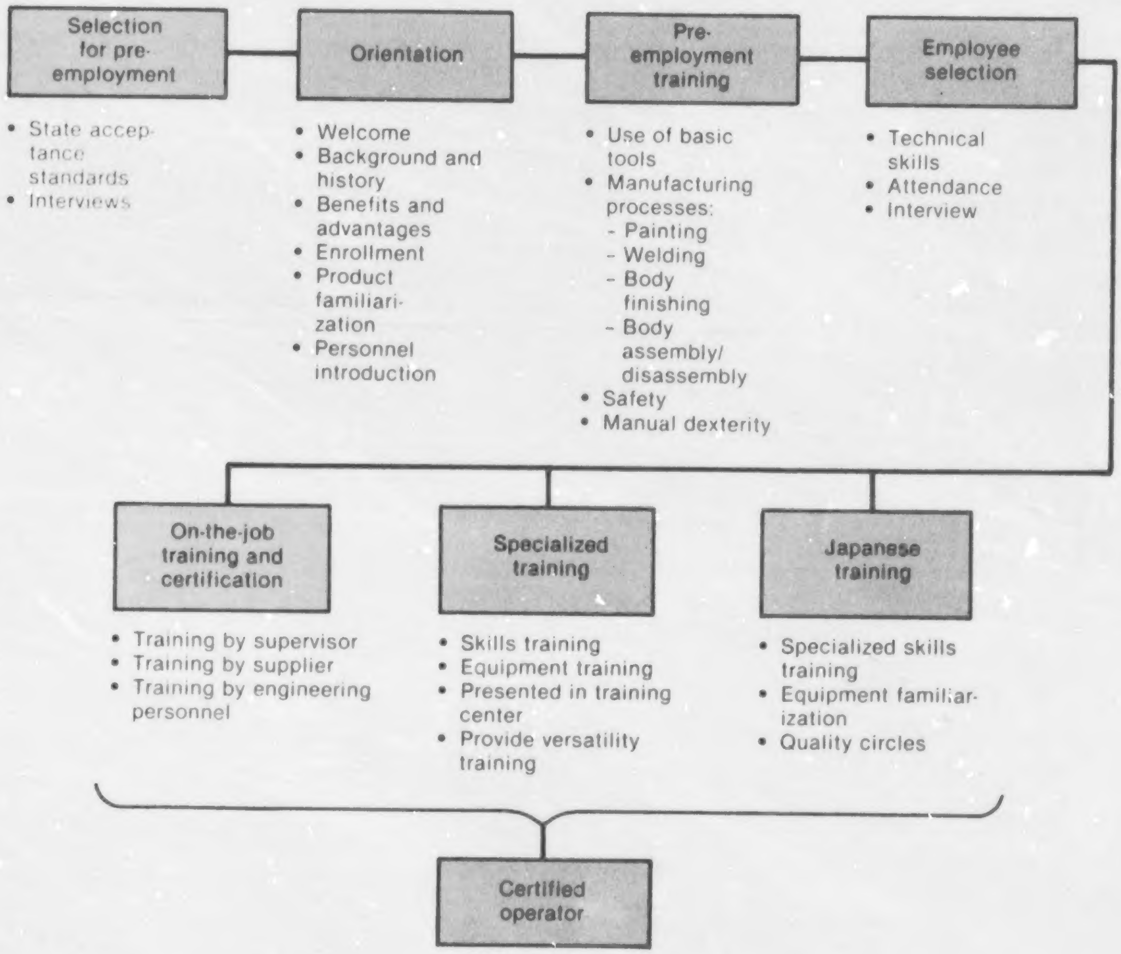
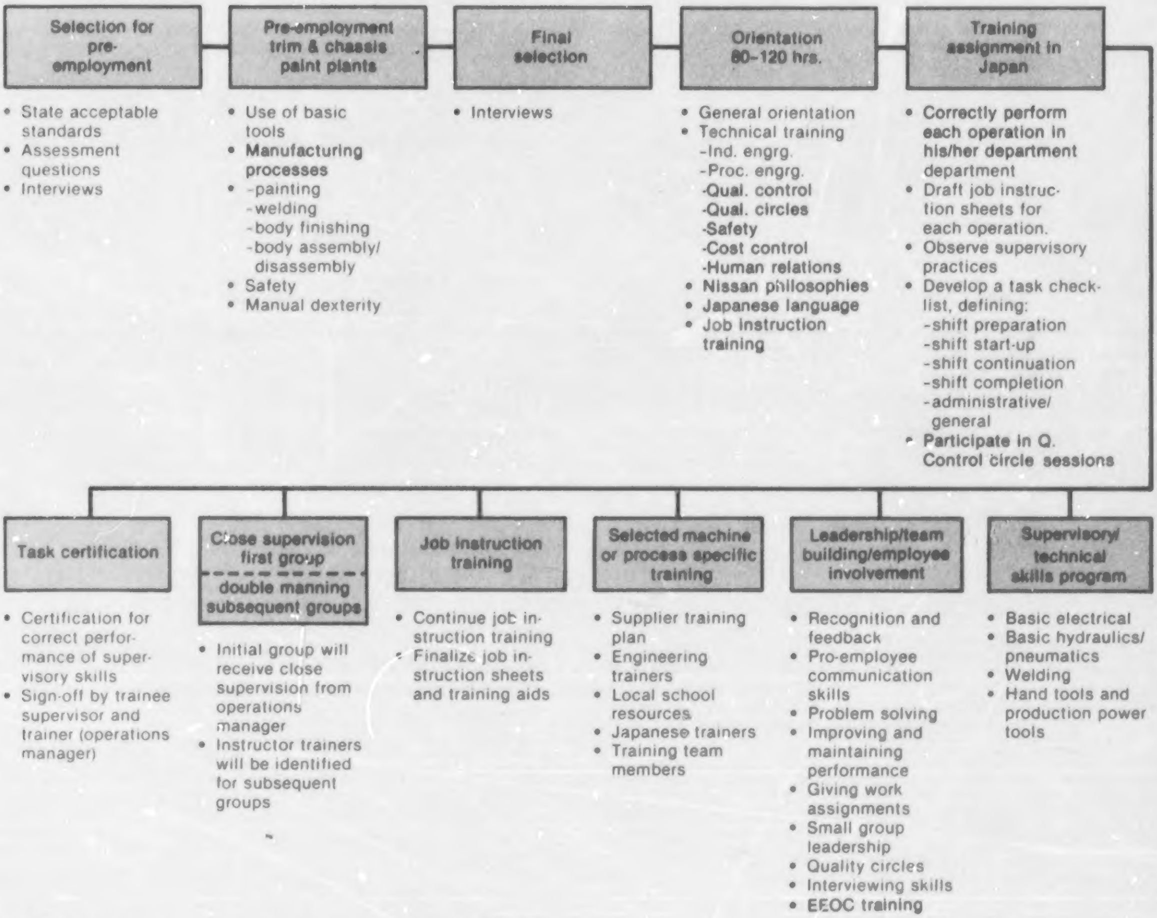
[100] "Survey of University Computer Graphics Instruction," *Computer Graphics World*, vol. 7, No. 1, January 1984, pp. 54, 56, 58.

Figure 26.—Manufacturing Technician Training at Nissan U.S.A.


Selection for pre-employment
• State acceptance standards
• Interviews
Orientation
• Welcome
• Background and history
• Benefits and advantages
• Enrollment
• Product familiarization
• Personnel introduction
Pre-employment training
• Use of basic tools
• Manufacturing processes:
- Painting
- Welding
- Body finishing
- Body assembly/disassembly
• Safety
• Manual dexterity
Employee selection
• Technical skills
• Attendance
• Interview
On-the-job training and certification
• Training by supervisor
• Training by supplier
• Training by engineering personnel
Specialized training
• Skills training
• Equipment training
• Presented in training center
• Provide versatility training
Japanese training
• Specialized skills training
• Equipment familiarization
• Quality circles
Certified operator

SOURCE: Nissan Motor Manufacturing Corporation U.S.A.

Figure 27.—Manufacturing Supervisor Training at Nissan U.S.A.



Selection for pre-employment
- State acceptable standards
- Assessment questions
- Interviews

Pre-employment trim & chassis paint plants
- Use of basic tools
- **Manufacturing processes**
- -painting
  - -welding
  - -body finishing
  - -body assembly/disassembly
- Safety
- Manual dexterity

Final selection
- Interviews

Orientation 80–120 hrs.
- General orientation
- Technical training
  - -Ind. engrg.
  - -Proc. engrg.
  - **-Qual. control**
  - **-Qual. circles**
  - **-Safety**
  - **-Cost control**
  - **-Human relations**
- **Nissan philosophies**
- **Japanese language**
- **Job instruction training**

Training assignment in Japan
- **Correctly perform each operation in his/her department** department
- Draft job instruction sheets for each operation.
- Observe supervisory practices
- Develop a task checklist, defining:
  - -shift preparation
  - -shift start-up
  - -shift continuation
  - -shift completion
  - -administrative/general
- **Participate in Q. Control circle sessions**

Task certification
- Certification for correct performance of supervisory skills
- Sign-off by trainee supervisor and trainer (operations manager)

Close supervision first group
double manning subsequent groups
- Initial group will receive close supervision from operations manager
- Instructor trainers will be identified for subsequent groups

Job instruction training
- Continue job instruction training
- Finalize job instruction sheets and training aids

Selected machine or process specific training
- Supplier training plan
- Engineering trainers
- Local school resources
- Japanese trainers
- Training team members

Leadership/team building/employee involvement
- Recognition and feedback
- Pro-employee communication skills
- Problem solving
- Improving and maintaining performance
- Giving work assignments
- Small group leadership
- Quality circles
- Interviewing skills
- EEOC training

Supervisory/technical skills program
- Basic electrical
- Basic hydraulics/pneumatics
- Welding
- Hand tools and production power tools

SOURCE: Nissan Motor Manufacturing Corporation U.S.A.

Table 55.—Robotics Degree Programs and Course Offerings in North America, 1982

State	Number
I. Robotics degrees and/or options in robotics as part of an engineering degree	
2-year schools	
Colorado	1
Florida	2
Illinois	1
Michigan	6
Ohio	1
South Carolina	1
4-year schools	
Florida	2
Michigan	1
New York	1
North Carolina	1
Oregon	1
Pennsylvania	1
South Carolina	1
Graduate-level schools	
Georgia	1
Illinois	1
New York	1
North Carolina	1
Pennsylvania	2
Texas	1
II. Robotics courses	
2-year schools	
Alabama	1
Arizona	1
Florida	1
Georgia	1
Illinois	3
Indiana	1
Iowa	1
Maryland	1
Michigan	3
North Dakota	1
Ohio	3
Tennessee	1
Wisconsin	2
4-year schools	
Arizona	1
Arkansas	1
California	4
Colorado	1
Delaware	1
District of Columbia	1
Florida	1
Georgia	1
Illinois	2
Indiana	2
Michigan	5
Mississippi	1
Missouri	1
Nebraska	1
New Jersey	1
New York	2
North Carolina	1
Ohio	2
Pennsylvania	1
South Carolina	1
Tennessee	1
Texas	1
West Virginia	1
Wisconsin	1
Graduate-level schools	
California	1
Delaware	1
Florida	2
Illinois	1
Indiana	1
Michigan	2
Missouri	1
New Jersey	1
New York	1
North Carolina	1
Ohio	1
South Carolina	1
Tennessee	1
Texas	2
Wisconsin	1
Canada	1
III. "Support courses" generally part of a robotics degree program	
2-year schools	
Alabama	2
Arizona	1
California	3
Colorado	2
Connecticut	1
Florida	1
Georgia	1
Illinois	6
Indiana	1
Iowa	4
Massachusetts	1
Michigan	2
Mississippi	1
Missouri	1
Nebraska	2
New Jersey	1
New York	3
North Carolina	6
Ohio	7
Oklahoma	2
Oregon	3
Pennsylvania	3
South Carolina	3
Tennessee	1
Texas	6
Virginia	1
Washington	3
Wisconsin	7
4-year schools	
California	1
Illinois	1
Indiana	1
Louisiana	1
Massachusetts	1
Michigan	1
Mississippi	1
New York	3
North Dakota	1
Ohio	3
Texas	1
Canada	1
Graduate-level schools	
California	1
Hawaii	1
Nevada	1
Ohio	1
Texas	1
Utah	1

SOURCE: Robotics International, *Directory of North American Robotics Education and Training Institutions.*

As noted earlier in this chapter, the instructional requirements for programmable automation are still emerging. **But even based on current skill requirements for automated manufacturing facilities, widespread use of programable automation would pose challenges (in the form of increased demand for the development of certain skills) to elementary, secondary, postsecondary, and continuing education. Industry-based and labor union-based instructional programs will also be affected by the increased need for technical instruction.**

The present capacities of the U.S. instructional system to prepare students for employment in computer-automated manufacturing facilities and other types of work environments are limited by shortages of equipment, inadequate facilities relative to present and potential future demand, and inadequate supply of quality instructors for technical and engineering education. In addition, shortages of science and math instructors on the elementary, secondary, and postsecondary level complicate the process of developing adequate basic skills in individuals who may wish to prepare themselves for careers in automated manufacturing. Shortages of state-of-the-art equipment and of technical instructors are also problems faced in industry-sponsored, in-plant instructional programs.

Based on OTA research, it is questionable whether the capacity represented by the U.S. education, training, and retraining system will be sufficient to meet the challenge of widespread use of programmable automation, should extensive adoption of programmable automation occur. Instructional institutions are willing and interested in meeting the challenge, but it is unlikely that they will be able to do so unless equipment and instructor shortages are resolved. In addition, unless stronger links are developed between industry, labor, educators, and government, it is questionable whether programs now in development and those that will be designed in the future will be in keeping with present and anticipated PA-related skills requirements. Intersector cooperation is also needed to ensure that labor market information is widely disseminated among all those affected by programmable automation: i.e., individuals preparing to enter the work force; institutions that provide education and career counseling services; employers who need the information for long-range planning; and labor unions, who require it to advise their members of the need to retrain or otherwise enhance skills.

Chapter 7

Programmable Automation Industries

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Chapter 7

Programmable Automation Industries

Summary

The principal programmable automation (PA) industries grew slowly in their early years. Development of the robot industry was dominated by entrepreneurs. The U.S. Government, through programs aimed at improving military procurement, contributed to the launch of other major PA industries, including computer-aided design (CAD) and numerical control (NC). Since the mid- to late-1970's, PA industries have grown rapidly even during the past recessions; they are expected to continue to do so throughout this decade. These industries are largely separate at this time, but a unified computer-integrated manufacturing (CIM) industry may emerge in the future.

Markets for programmable automation are strongly international, and various forms of interfirm cooperation blur distinctions among firms by nationality. Further, PA suppliers are providers of services as well as goods; the role of hardware and of manufacturing among these industries is considered much less strategically important than the role of software, controls, and various forms of customer support.

OTA's evaluation of PA industries reveals several broad themes. These are: 1) there has been a discrepancy between vendor and buyer views of needs and capabilities; 2) systems planning and other services are key features of PA supply, while manufacturing itself plays a smaller role; 3) vendors are likely to package and/or distribute hardware and software elements made by several firms; 4) both large and small firms have played distinctive roles in the development of PA markets; and 5) governments have had a major influence on PA market development.

Introduction

CAD, robots, NC machine tools, flexible manufacturing systems (FMS), and other programmable automation equipment and systems are supplied by industries that are currently more or less separate. Of the principal PA industries, the NC industry is the oldest and largest, dating from the 1950's. While CAD and robots were available by the 1960's, significant markets for these technologies did not emerge until the 1970's. These industries are now growing quickly.

The previously slow and uneven growth seen in markets for automation goods and services reflects a persistent mismatch between commercially available technologies and the willingness and ability of users to purchase them. This may now be changing. Recent technological and economic trends—including improvements in computer control, improvements in equipment interfacing, cost reductions, and a growing interest in manufacturing productivity—have fueled rapid growth in PA sales during the last few years. These trends also have blurred some of the distinctions among automation industries. They suggest that a single market encompassing CIM may eventually emerge. Whether or not this happens, industry analysts forecast that the combined PA market may grow from under $5 billion in sales today to $20 billion to $30 billion by 1990.*

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*Note that published market estimates vary enormously, in part because of different approaches to market definition. The Arthur D. Little consulting firm, for example, contends that the 1982 market was over $24 billion, including $11.5 billion in "computing technology," $6.26 in "CAM," $6.1 billion in "automated materials handling," and $0.26 billion in robots. This estimate appears to use very broad categories that may apply to nonprogrammable automation products. *American Metal Market/Metalworking News*, Sept. 26, 1983.

This chapter focuses on the producers and sellers of PA equipment and systems, who comprise the various PA industries. The discussion provides perspective on their roles as: 1) so-called "high-technology" enterprises, and 2) sources of employment. Insights into the current and potential role of these businesses in the U.S. economy is provided by describing their industrial structure (trends in the number and types of firms), competitive conduct (e.g., product strategies), and their financial performance. This task is made difficult by the uneven quality and availability of industry data; some industry data (e.g., for robots) are available only through trade associations and are questioned even by trade association staff.[1] Since automation industries are growing and changing, descriptions of current characteristics offer only a snapshot. Consequently, the chapter addresses changes in automation industries over time.*

Although automation industries are growing relatively rapidly, much of their impact on the economy will be realized indirectly. This is because their principal customers are other businesses, which adopt automation to use in producing consumer and other producer goods, from appliances to construction equipment. The direct contributions of these customers to the gross national product (GNP), the balance of trade, and other indicators of national economic well-being will thus derive in part from the use of automated equipment and systems; the size of those contributions may reflect the extent and success of PA applications. This is one of the reasons why many analysts believe that programmable automation will be increasingly important to the Nation's industrial base and, ultimately, to national security.

The broader the customer base for programmable automation, the greater the direct economic contribution of automation businesses. For reference, it should be pointed out that the machine-tool industry, a principal supplier of capital goods to metalworking manufacturing industries, is very small in terms of output and its own employment (under 70,000 employees in 1983 and under 80,000 employees in 1982, down from about 100,000 in 1980; about two-thirds are production workers).[2] By contrast, the computing equipment industry, which is less labor-intensive than the machine tool industry and which serves both industrial and consumer markets, is much larger (employing about 3,420,000 in 1982).[3] PA producers come from both of these industries and from others.

The ultimate growth and size of domestic programmable automation industries will be constrained because automation markets are and always have been international. Although the United States initiated the production and use of many types of PA, these technologies were adopted relatively quickly abroad. Japan, the United Kingdom, France, Italy, West Germany, Sweden, and Norway are each significant sources of at least one type of programmable automation. This parallel development of industries may be due, in part, to foreign government support for automation development and use, although it is difficult to evaluate the effectiveness of such government support actions (see ch. 9). **At present, U.S. producers dominate U.S. markets for programmable automation.** They also export automation products, and some U.S. firms have invested in the production of PA equipment and systems abroad. For example, Unimation (now part of Westinghouse) has a robot plant in Telford, England, and Cincinnati Milacron has several European machine tool plants. Unless governments restrict access to national markets, international competition in automation markets will continue to be strong.

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[1] See Jake Kirchner, "Government Must Support Robotics, Says RIA President," *American Metal Market/Metalworking News*, Sept. 19, 1983. By contrast, note that data on equipment production and use in Japan appear to be much more thorough and accurate.

*Because PA industries are evolving relatively quickly, it is hard to describe current conditions in enduring terms. Data presented in this report reflect information available up to late March 1984.

[2] National Machine Tool Builders Association, *1983-84 Economic Handbook of the Machine Tool Industry*.

[3] Electronic Industries Association, *1983 Market Data Book*.

Near-term growth of domestic programmable automation industries will depend on whether domestic economic conditions are favorable to investment. The recent recessions eroded the dramatic growth rates observed for automation sales toward the end of the last decade. Nevertheless, industry analysts commonly forecast rapid PA market growth for the decade. For example, Predicasts, Inc., has forecast that the combined market for "manufacturing computers," CAD systems, machine tools and controls, and robots will grow over 15 percent annually between 1982-1987.[4] Sales will double, according to that analysis, attaining almost $15 billion by 1987. The analysis assumes a GNP growth rate in real terms of 3.8 percent per year. A more sluggish economy would therefore mean lower PA sales.

Industry growth will also depend on the ability of American managers to justify investments in programmable automation and to become adept at using it. Inability to do both has limited the diffusion of PA technologies.* In the future, attitudinal obstacles are likely to be lower because widespread concern (sometimes bordering on hysteria) about international competitiveness, as well as trade association activities, technical and trade publications, and various informal networking activities are all familiarizing growing numbers of businessmen with PA's nature and potential benefits and costs. Conferences sponsored by the Society of Manufacturing Engineers (SME) and other professional and trade associations during the early 1980's have included numerous sessions on financial analysis and other activities designed to help engineers persuade upper management to support automation. Meanwhile, anecdotal evidence suggests that in a number of companies upper management is demanding programmable automation, even before specific applications are identified.

The remainder of this chapter addresses the development of the CAD, NC (with FMS), and robotics industries; characterizes related industrial activity; examines the potential for a CIM market; and derives conclusions about key traits of PA industries. Contrasts between countries are examined to the extent that data permit.

Principal Programmable Automation Industries: Evolution and Outlook

CAD

History

The first CAD systems were developed by users. In the late 1950's and early 1960's, aircraft and automobile companies, whose products are very complex, developed their own software to aid in product design and engineering. Pioneer users, such as GM and Boeing, were necessarily large firms because early CAD and engineering required the use of expensive mainframe computers. The diffusion of CAD during the 1960's was slow, limited by the cost of hardware and the requirements for extensive engineering and software support. Most early users were defense contractors in the aerospace and electronics industries, where the U.S. Department of Defense (DOD) supported CAD development and use.

A formal market for the purchase and sale of CAD emerged during the 1970's, due in part to improvements in computer hardware and in operating systems which enabled more firms to afford computers for increasingly powerful work. Using microprocessors, mini- and microcomputers made many tasks, including basic two-dimensional computer-aided drafting, possible without a mainframe computer. The electronics industry, from component manufacturers to computer makers, provided a growing market for CAD systems. Compared to mechanical manufacturing firms, electronics firms were more comfortable with computer-based technology. Their integrated-circuit (and circuit-board) design applications were fundamentally two-dimensional, and therefore well-suited to early CAD. Also, the growing complexity of integrated circuits made computer assistance in design increasingly necessary; manual design would require exorbitant amounts of time and manpower. Another early commercial application was in two-dimensional drafting for mechanical design.

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[4] "Robots, CAD/CAM to Lead 1980's Automation Surge, Says Predicasts," *The Battery Man*, November 1983.

*While indirect production costs tend not to vary with choices of conventional equipment, they can vary enormously for PA. Conventional methods of investment analysis have been unable to capture all changes in costs. Also, the conventional emphasis on investments with quick paybacks overlooks the long-term benefits of flexibility conveyed by PA.

During the 1970's, improvements in software for two- and especially three-dimensional CAD fueled a market expansion into mechanical and mapping as well as architecture, engineering, and construction (AEC) applications. Some of these advances stemmed from Government-funded efforts, which emphasized aerospace and electronics applications for CAD and the integration of CAD and CAM.*

Between 1973 and 1981, the CAD system market grew from under $25 million in annual sales to over $1 billion.[5] Hardware and software makers entered the CAD market with specific applications and packaged systems. Firms that entered the CAD market to fill an applications niche typically grew by increasing the variety of CAD applications they could serve. Turnkey vendors, who assembled and installed systems from components made by various sources, also provided training, support, and both standard and custom software. These vendors, led by Computervision, dominated the market. They were successful because their customers lacked the technical sophistication to assemble their own systems (but knew when a turnkey system would work for them), and because their typical reliance on external sources for hardware and other inputs allowed them to incorporate new technology relatively quickly. Accordingly, in addition to system vendors, the CAD industry grew to include groups of hardware and software producers serving both turnkey firms and users directly.

During the mid-to-late 1970's, the Japanese and European markets (especially those in England, France, Sweden, and Norway) grew rapidly, and markets in less developed countries began to emerge (primarily for mapping applications). U.S. firms dominated the CAD market, both within the United States and abroad, largely because of their perceived software and systems engineering strengths.

Recent and Contemporary

The size of the worldwide CAD market is currently about $1.6 billion in annual sales.[6] Five U.S. vendors account for about 80 percent of the market,[7] although many firms have entered the CAD market recently and others may soon enter. In total, there are perhaps 100 vendors today. Table 56 shows recent market development as a function of application. Table 57 shows recent market share estimates.

The current CAD market contains segments distinguished by type of computerization: mainframe, minicomputer, and microcomputer/workstation. From this perspective, mainframe-based systems are the most sophisticated, microcomputer-based systems the least. The market can also be segmented by discipline of application, although there is substantial overlap among disciplines: mechanical (e.g., design of components for future fabrication); electronics (e.g. wiring, printed circuit-board design, integrated circuit design); and

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*Government-sponsored programs, such as the DOD ICAM and NASA IPAD programs, are described in ch. 8.

[5] See Roger Rowand, "Manufacturing Makes a Move Into the Future," *Automotive News* (Detroit: Automotive News Extra, May 23, 1983). Note that most published sales estimates refer to turnkey systems sales and associated revenues.

[6] Thomas Kurlak, "CAD/CAM: Review and Outlook," Merrill Lynch Capital Markets, October 1983.

[7] Ibid.

Table 56.—Estimated Worldwide CAD Market (Turnkey) by Application
(dollars in millions)

	1980	Percent growth	1981	Percent growth	1982	Percent growth	Est. 1983	Percent growth	Est. 1984	Percent growth
Mechanical	$235	+84	$380	+62	$ 460	+21	$ 552	+20	$ 825	+49
Electronic	177	+81	235	+33	310	+32	430	+39	645	+50
Architecture and engineering	87	+50	138	+59	210	+52	335	+60	485	+45
Mapping	13	+128	111	+52	154	+39	190	+23	240	+26
Other	20	+11	30	+50	73	+43	93	+27	140	+51
Total	592	+77	894	+51	$1,207	+35	$1,600	+33	$2,335	+46

SOURCE: Thomas P. Kurlak, Merrill Lynch Capital Markets.

AEC (e.g., piping, architectural drafting). Mechanical applications, especially those using 3-D modeling, tend to be more complex than the others. The so-called high end of the market involves larger computers and more sophisticated software, sold as systems costing several hundreds of thousands of dollars. Software alone may amount to anywhere between 25 to 50 percent of system cost. The low end is comprised of workstations and simpler software packages. These systems are available for under $100,000, and some (based on Apples and other small computers) cost as little as $10,000 (or less).[8] One commercial study has estimated that sales of CAD systems costing under $100,000 will grow from the 5 percent share of total CAD sales reached in 1981 (580 systems valued at $36 million) to 20 percent by 1986 (10,600 systems valued at $544 million).[9]

Two changes in computing hardware have had a big impact on the CAD industry. First, in the late 1970's, the introduction of 32-bit minicomputers (with virtual-memory operating systems), offering improvement over the 16-bit standard, changed the competitive ranking within the industry and broadened the market. The first firm to offer 32-bit CAD systems, Intergraph, increased its market share significantly. More importantly, the increase in computing power made minicomputers competitive with mainframes across a variety of CAD applications, such as simulation and solid modeling. This development opened the market to customers who could not have purchased mainframe-based systems.

Second, the introduction of low-cost, microcomputer-based CAD systems in 1981 also broadened the CAD market. While these CAD systems—generally stand-alone workstation units—are less powerful than systems with larger computers, they make basic CAD available to a larger group of customers, including small manufacturers and, particularly, AEC firms. Microcomputer-based systems have thus enlarged the portion of the CAD market serving nonmanufacturing firms, potentially increasing the overlap between CAD and other computer and computer-graphics applications. One study has predicted that the installed base of microcomputers and workstations for scientific and engineering applications will grow from under 9,000 units in 1983 to more than 275,000 in the next 10 years.[10] Others anticipate even higher growth rates.

Although hardware is the largest cost element for CAD systems, current competition in the CAD market centers on software. This is because software determines what a system can do, while hardware largely determines how fast a task can be done. Moreover, because CAD system vendors deliver up to 500 to 600 systems a year, it tends to be uneconomical for them to produce their own hardware.* In-

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[8] For example, the CAD-1 package for use with Apple Computers, designed for architects and engineers, is available for about $1,000. (Bob Schwabach, "Computer paints a pretty picture," *St. Paul Dispatch*, Nov. 16, 1983.)

[9] Eric Teicholz and Peggy Kilburn, "Low-Cost CADD at Work," *Datamation*, Jan. 1983.

[10] See "CAE Terminals in Demand," *Computerworld*, May 23, 1983. Another important hardware development is the growing use of raster display terminals.

*Computervision has been an exception; it has produced its own CPU—although it has recently decided to buy and resell large IBM computers—and it also markets Sun Microsystem workstations. See: Ed Scarnell, "IBM CAD/CAM Thrust Linked to Remarketers," *Computerworld*, Aug. 22, 1983.

Table 57.—Estimated Turnkey CAD Market Shares

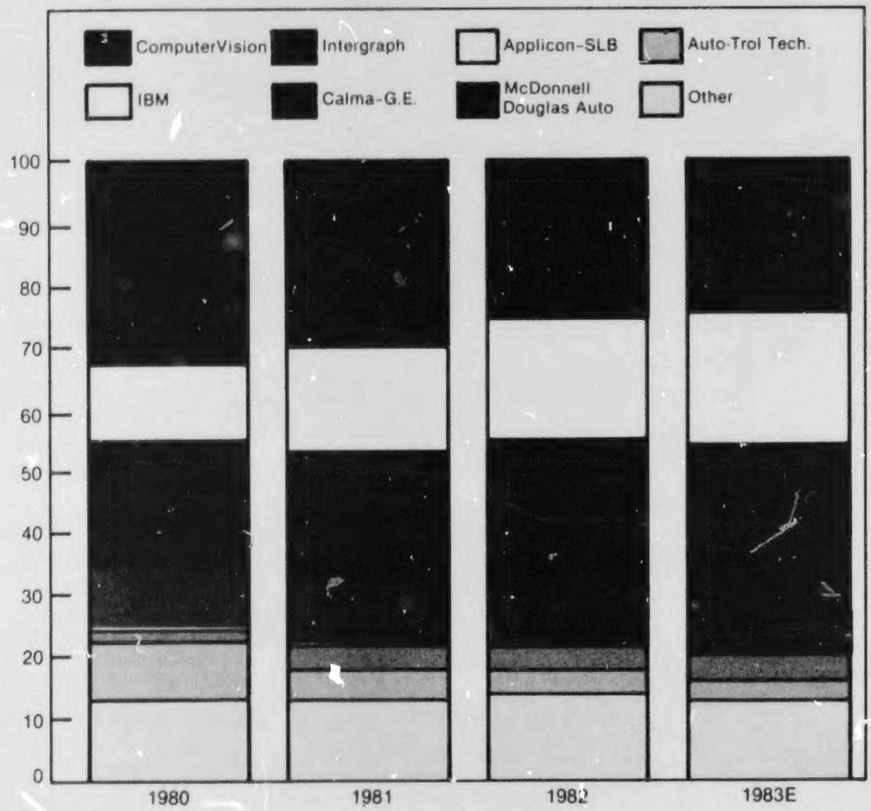
	1980	Percent	1981	Percent	1982	Percent	1983 (est.)	Percent
Computervision	$191	32	$271	30	$ 325	27	$ 395	25
IBM	71	12	145	16	225	19	340	21
Intergraph	56	9	91	10	156	13	246	15
Calma-G.E.	62	10	100	11	140	12	195	12
Applicon-SLB	68	11	84	9	96	8	100	6
McDonnell Douglas Auto	14	2	35	4	46	4	60	4
Auto-trol Technology	51	9	48	5	44	4	49	3
Other[a]	79	13	120	13	175	14	215	13
Totals	$592	100%	$894	100%	$1,207	100%	$1,600	100%
Growth			+51%		35%		33%	

[a] Control Data, Prime, Digital Equipment, Data General, Sanders, Gerber Scientific, etc.

Note: Control Data revenues estimated at $61 million for 1982, $76 million for 1983, $106 million for 1984. Service estimated at 60% for 1983, 40% for 1984. Turnkey sales ($30 million for 1983) from workstations and 800 series.

SOURCE: Thomas Kurlak, Merrill Lynch Capital Markets.

Estimated Turnkey CAD Market Shares



NOTE: Control data revenues estimated at $61 mil for 1982, $76 mil for 1983, $106 million for 1984. Service estimated at 60% for 1983, 40% for 1984. Turnkey sales ($30 mil for 1983) from workstations and 800 series.

SOURCE: Thomas Kurlak, Merrill Lynch Capital Markets.

stead, they rely on a few mass-producing hardware vendors for their equipment.* CAD vendors' contributions to the product come from software development, systems integration, applications engineering, and other support activities—they produce services that accompany the goods they sell. The costs of replicating software, compared to hardware, are negligible. The principal fixed costs born by turnkey vendors are for R&D and for software development, which may range from tens to hundreds of thousands of dollars. R&D tends to run at 10 to 12 percent of sales for major CAD vendors; this compares with an average of about 8 to 10 percent for major firms in the data-processing industry.[11]

A variety of firms have entered the CAD market or expanded their involvement through merger and acquisition, product licensing, and product innovation. Many computer vendors (e.g., DEC, Sperry Univac, Honeywell, Harris, Prime, Data General, Perkin-Elmer, and Hewlett-Packard) have entered the CAD market, often by selling systems with software licensed from other firms. IBM, for example, offers its hardware with Lockheed's CADAM software; it has recently moved to provide its hardware through other software developers acting as so-called value-added remarketers. Large diversified companies (e.g., GE and Schlumberger) have also entered the CAD market, principally through the acquisition of smaller CAD or software firms. GE, for example, bought Calma; Schlumberger bought Applicon.

In addition, independent software suppliers have proliferated to meet special applications needs and to meet the growth in demand associated with the spread of micro-based systems.** One group of specific applications served by software firms is computer-aided engineering. In this area, MacNeal-Schwendler Corp. and Swanson Analysis offer widely used finite-element analysis packages (MSC/Nastran and ANSYS, respectively). Such specific applications software is typically supplied as part of system packages, or sold directly to users. Software for microcomputers, however, tends to be sold in higher volumes and at lower costs, using networks of distributors and dealers. Other participants in the broader CAD market include producers of such related items as documentation and microfilm generators. These items have come into demand as CAD users developed or perceived new needs associated with CAD. At least four technical publishing companies, for example, started up during the first half of 1983 alone.

A growing but hard-to-measure factor in the CAD market is the participation of CAD users who have developed their own systems—although their role remains small. External sale of internally developed CAD systems allows users to gain an additional return on their investments in software development. Historically, users who developed their own systems did not enter the CAD market for several reasons: Their applications tend to be highly customized; it is difficult and costly to prepare for external marketing; and users may prefer to retain their systems to enhance their own profitability. Lockheed, for example, found meeting divergent market needs to be a major challenge during its first 15 years selling CADAM. IBM is known to have developed its own CAD software, but markets CADAM software instead (it also markets less sophisticated software of its own design).

Ford recently decided to market, through Prime Computer, a 3-D wire frame design and drafting system it developed and has used for the past 10 years; it generalized the system from automotive applications to design of structures, mechanical components, and systems.[12] And Chrysler plans to develop with Control Data advanced mechanical CAD and CAM software, which Chrysler would use for vehicle design and development and Control Data would market as part of a line of computer goods and services.[13] Other user-producers include McDonnell Douglas (Unigraphics), the French firm Dassault (CATIA), and Northrop (NCAD).

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*The Digital Equipment Corp. VAX line has been particularly popular for CAD systems.

[11] Personal communication Terence Carleton, analyst, Kidder, Peabody & Co.

**The market research firm IDC estimates that annual sales of microcomputer software overall will grow from $965 million in 1982 to nearly $7.5 billion in 1987. Independent firms now supply about 50 percent of that software, and their share may grow to 57 percent by 1987. *Computerworld, March 14, 1983.*

[12] *Computerworld*, June 6, 1983.

U.S. firms continue to dominate both U.S. and foreign markets for CAD systems. Ninety percent of the U.S. CAD market is served by U.S. firms.[14] Major CAD vendors operate overseas facilities to serve foreign markets. Intergraph, for example, has a customer support center in the Netherlands that serves customers in Europe and the Middle East. The center carries out repair, training, and other customer support activities. U.S. CAD systems are generally sold in Japan through Japanese distributors.[15]

The international market appears to be experiencing a substantial degree of international merger, acquisition, and especially licensing activity. European firms have developed important CAD software, but Europe lacks significant suppliers of CAD hardware. Consequently European software has been licensed to U.S. firms (e.g., Evans and Sutherland, Prime, Computervision) that package CAD systems, and U.S. firms have purchased foreign companies. For example, Evans and Sutherland bought Shape Data (United Kingdom), and Computervision bought Cambridge Interactive Systems (United Kingdom) and Grado (West Germany). Such "cross-fertilization" is a typical means of entry into foreign markets.

The Japanese role in the CAD market remains limited and focused on hardware. Japanese vendors tend to be computer firms, rather than turnkey companies; they sell systems providing American software under license, although they are developing their own software internally and through a government-sponsored consortium.

Likely Change

The CAD market will remain relatively dynamic for the next several years. Industry analysts predict that it will grow at rates between 30 and 50 percent per year; some forecasts for the CAE sub-market anticipate even higher rates of growth. While industry spokesmen believe that most of the Fortune 500 companies already use CAD, growth will come from both existing and new customers. Factors such as expected improvements in system capabilities, especially for 3-D modeling; greater ease of use; and reductions in costs for given capabilities will widen the range of customers by size, industry, and application area. These trends will create new niches and ancillary-product markets, and they will change patterns of competition. Most analysts expect that mechanical applications and CAE systems will become more prominent in the CAD market, reflecting both technological development and the expected spending growth of manufacturers as they recover from the recent recessions. One source expects that mechanical design will comprise about half of CAD applications, and that CAE will account for about 20 percent of the workstation market, by 1987.[16] Mapping and facilities management applications are also expected to grow, serving government, utility, and natural resource development customers.

CAE has been a major factor in the growth of the custom microchip market.[17] Expected growth in the microchip market overall and the custom share will spur CAE sales. In the mechanical area, future use in forging-die design, for example, will be encouraged by an Air Force project to develop a generic forging-die CAD/CAE system for aerospace applications. The project involves a consortium of firms.[18]

While the market is expected to grow rapidly, the number of vendors may stabilize or fall. Consolidation is occurring already, as both turnkey firms and computer companies acquire software houses and expand their offerings. Computervision, for example, recently arranged to buy the Organization for Industrial Research, a privately held CAD software firm with strength in group technology. IBM's growing involvement in the CAD market, particularly at the high end but potentially in low-cost systems, is also likely to promote consolidation.

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[13] "Control Data and Chrysler to Make Software," *Automotive News*, Dec. 12, 1983.

[14] OTA Automation Industries Workshop.

[15] Jack Thornton and Tsukasa Furukawa, "GE, Japanese Plan Automation Venture," *American Metal Market/Metalworking News*, Nov. 1, 1982.

[16] "1987 CAD Market Estimated at $6.9 Billion," *American Metal Market/Metalworking News*, Dec. 5, 1983.

[17] Bohdan O. Szuprowicz, "Microelectronics Here Showing Massive Growth," *Computerworld*, Dec. 5, 1983.

[18] Bruce Vernyi, "Shultz Steel Selected by Air Force to Develop Forging Die CAD System," *American Metal Market/Metalworking News*, Jan. 30, 1984.

One trend that may affect sales is the growth in firms offering CAD services and/or related facilities to manufacturers, usually small companies which cannot afford CAD on their own or companies of any size that cannot meet extraordinary needs. These businesses resemble computer time-sharing service bureaus that provide general-purpose computing services. Danly Machine Corp., for example, will sell CAD services through its CAD/Share Service Center to automotive suppliers. In particular, it will provide authorized tool and part vendors with computerized design data to enable them to use CAD in bidding for contracts and performing design and production work for the Buick division of GM. It will also provide CAD training and consulting services.[19]

Some CAD service bureaus provide complementary manufacturing "services." For example, Camax Systems, Inc., sells time on computers to customers designing prototype tools, which it will also manufacture for them.[20] NCR and Control Data Corp. have developed an electronic CAD design center that allows integrated circuit makers and systems houses to design at engineering workstations, have access to a supercomputer, use semicustom circuit "cells," check circuit performance, and arrange for chip fabrication.[21]

As the installed base of CAD systems grows, the role of vendor services (e.g., software updates, related training) will grow. This growth will reflect in part the growth in sales to smaller firms, which traditionally buy a variety of services they cannot afford to perform themselves. Already (although in part because the recession damped new system sales) Computervision has seen its share of revenues from services to existing customers rise significantly in the last few years.[22] Also, CAD vendors contacted by OTA appear to be increasing their efforts in the area of training, corresponding in part to growth or change in software offerings. The growing role of services parallels the experience in the computer industry, where service activities and their proportional contribution to revenues increased with the spread of computer systems.

The extent to which CAD vendors will address the broader problems of computer-based integration of manufacturing is a key uncertainty for the future of the industry. Compared to other types of firms, especially industrial machinery vendors, CAD vendors may be especially well-positioned to link CAD to CAM. The design-to-production chain begins with CAD, and CAD firms are already developing systems for modeling production activities and communicating production instructions to other equipment. Computervision, for example, offers systems that program NC machine tools, robots, and coordinate-measuring machines; design and model manufacturing cells; design tooling, molds, and dies; and perform computer-aided process planning. It offers multifunction systems, such as a system for plant design, engineering, construction, and management. Prime Computer will market a British computer-aided process planning system which can be integrated with CAD; while McAuto purchased Insight Technology, which developed a CAD system terminal that can be linked to NC machine tools.

As the above examples suggest, many vendors are broadening their lines through acquisitions. Also, some vendors are developing their own software to facilitate CAD and CAM links. McAuto, for example, is developing expert systems for evaluating robot system configurations.[23]

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[19] "Danly Sets Up CAD/CAM Office for Auto Industry," *American Metal Market/Metalworking News*, Nov. 7, 1983.

[20] "Firm Sells CAD/CAM Computer Time to Clients," *American Metal Market/Metalworking News*, Sept. 26, 1983.

[21] See *CAE*, November—December 1983.

[22] Jack Thornton, "Turnkey CAD/CAM Producers Confront a Difficult Year," *American Metal Market/Metalworking News*, Jan. 3, 1983.

Some vendors (e.g., Apollo) are moving away from dedicated CAD terminals in favor of general-purpose engineering/professional workstations. These workstations would accommodate not only drafting and design, but also research, software development, and "office automation" functions; they would thus facilitate shifts in customer activities and software preferences and lower the risk of hardware obsolescence. Multifunction workstations could facilitate manufacturing integration, especially when combined with sophisticated data communication systems linking engineering, production, and general corporate databases. An alternative approach is to market low-cost, dedicated CAD workstations which can be linked to mainframe computers for other functions that use a common database. Some analysts expect sales of such low-cost microcomputer workstations to grow at the expense of minicomputer-based systems, a development that could pose problems for turnkey vendors.[24]

For other CAD vendors, the term "CAD/CAM vendor" will continue to be misleading, since their products serve only design or drafting purposes. Because a market for basic CAD will remain to serve small manufacturers and nonmanufacturing customers, the division of the market between small, "niche" firms and low-cost CAD firms on the one hand, and large, integrated system-oriented firms on the other is likely to deepen. Also, firms not seeking to integrate CAD and CAM may be subsumed by the larger business graphics market, depending on the complexity of their systems.

International competition and trade trends for CAD will depend on how CAD products and markets develop abroad and whether protectionist measures are invoked.* A major uncertainty is the future role of the Japanese in the CAD market. The delayed entry of Japan into this market makes it hard to forecast Japanese competition in CAD, although there are now major efforts under way in Japan to develop CAD software and Japanese companies are actively involved in producing graphics peripherals (e.g., displays, printers, and plotters). However, the Japaneses could concentrate on gaining benefits from the use of sophisticated CAD systems in designing integrated circuits and other products, rather than from the the sale of CAD systems.

Numerical Control and Flexible Manufacturing Systems

History

Numerical control (NC) is the oldest of the programmable automation technologies and markets. DOD underwrote the development of the technology in the 1940's and 1950's, and required its use by principal aerospace contractors, thereby assuring the launch of NC production. It also fostered the adoption of APT as the standard NC programing language, and it continues to purchase machine tools through prime contractors as part of the procurement process.

The NC market is a subset of the broader machine-tool market, which contains two principal divisions: metal-cutting machine tools (e.g., lathes, and boring, milling, and grinding machines—SIC 3541) and metal-forming machine tools (e.g., presses, and boring, punching, shearing, and bending machines—SIC 3542).* However, the market for NC machine tools can be treated separately from the overall machine-tool market, inasmuch as customers do not consider NC and conventional machine tools to be alternatives.** This has been increasingly the case: As NC technology has improved, as the cost of controls has fallen, as computerization has improved, and as applications have grown more complex and costly, many machine tool buyers have come to prefer NC equipment to conventional equipment. Also, customers have grown to understand how and why NC and conventional costs differ, becoming more willing to bear the higher initial cost of adopting NC.*

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[23] Lauri Griesen, "McAuto Working to Add Dynamic Parameters, Expert Systems to Robot Programming Software," *American Metal Market/Metalworking News*, Dec. 26, 1983.

[24] Thomas Kurlak, "CAD/CAM: Follow-Up to Opinion on Changes," Merrill Lynch Capital Markets, Dec. 7, 1983.

*For example, a Norwegian firm, Kongsberg, is doing very well in the European CAD market.

*Other components of the machine tool industry include makers of special dies, tools, jigs and fixtures (SIC 3544), machine-tool accessories (SIC 3545), and other, not-elsewhere-classified metalworking machinery (SIC 3549).

**Note that available data do not always make clear what pertains to NC production and what to machine tools overall.

The "machine-tool industry" has historically referred to builders of machine-tool bodies.** The high cost of developing controllers (estimated to be between $1 million and $5 million) and the tendency for controller cost to fall with high-volume production generally deterred machine-tool builders from building their own controllers. Instead, they bought controllers from firms serving both machine-tool builders and other groups of customers. In 1981, 22 companies made positioning-type (direct data entry) NC controls, 16 companies made continuous path-type (computerized data entry) controls, and 23 made dial or plugboard-type controls. Shipments in 1982 exceeded $192 million; 1981 shipments exceeded $273 million.[25]

The machine-tool industry has had a large number of firms, given the small sales volume of the industry. Many of these firms are small. The 1963 Census of Manufactures counted 1,146 companies with 1,167 establishments, only 415 of which had 20 or more employees. The 1977 Census of Manufactures counted 1,343 establishments, 469 with at least 20 employees.[26] More recent data indicate that there are 1,285 companies with 1,345 establishments, two-thirds of which have fewer than 20 employees. The 20 largest companies account for 55 percent of industry shipments; the 50 largest account for 75 percent.[27]

Because NC hardware was relatively expensive, and because its use required access to computers and special support personnel, training, and maintenance, early production and use of NC was concentrated among relatively large firms. Although some smaller aerospace subcontractors did adopt NC in the 1960's, small firms were very slow to adopt NC. The diffusion of NC accelerated in the late 1960's. Between 1964 and 1968, unit shipments of (U.S.) NC machine tools virtually doubled; although unit shipments fell briefly in the early 1970's, they about doubled again in the period 1968-78, and rose over 150 percent between 1978 and 1981.[28] During this period, the variety of NC equipment also grew. Sales of NC machining centers (multifunction machine tools made possible by NC technology and the advent of automatic tool changers) grew by over 300 percent between 1970 and 1980.[29] Nevertheless, by 1978 only 2 percent of machine tools in use were numerically controlled; by 1983, that proportion was 4.7 percent.[30] [31]

Meanwhile, growth in demand for industrial equipment fell overall in the 1970's compared to the 1960's, and the relative importance of machine tools in particular also declined. Key metalworking markets grew slowly or shrank in the 1970's due to changes in customer sales patterns, closing of less efficient factories, and increased offshore production. Although booming investment by commercial aerospace and automobile industries caused sales to surge in the late 1970's, the principal machine tool buyers were the dominant firms in different metalworking industries, who could afford major modernization efforts.[32] The decline in the machine-tool proportion of total expenditures for equipment appears to be due in part to the increase in productivity of individual machine tools (reflecting improvements in cutting tools and other changes as well as the implementation of NC and CNC); productivity improvements allow customers to buy fewer (albeit sometimes more expensive) machines to do a given amount of work. The decline in the machine-tool proportion also reflects changes in product design and composition that lower the amount of machining performed. The long-term market decline exacerbates the impact of import competition; it also makes sales to smaller firms and other new categories of customers more important.

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*In some cases customers retrofit or rebuild older machines to add NC capability; this is usually cheaper than buying new NC equipment. However, machine performance tends to be lower than that provided by new NC equipment.

**However, machine tools are often sold by nonmanufacturer distributors.

[25] U.S. Department of Commerce, Report No. MA-36A.

[26] National Machine Tool Builders Association, *1983-84 Handbook of the Machine Tool Industry.*

[27] Eli Lustgarten, Vice President, Paine, Webber, Mitchell, Hutchins, personal communication.

[28] National Machine Tool Builders Association, *1983-84 Handbook of the Machine Tool Industry,* and U.S. Department of Commerce; latest data are incomplete, to avoid disclosure.

[29] National Machine Tool Builders Association, *1983-84 Handbook of the Machine Tool Industry.*

[30] "The 13th American Machinist Inventory of Metalworking Equipment 1983," *American Machinist,* November 1983.

[31] National Machine Tool Builders Association, *1983-84 Handbook of the Machine Tool Industry.*

[32] Garry J. Schinasi, "Business Fixed Investment: Recent Developments and Outlook," *Federal Reserve Bulletin,* vol. 69, January 1983; John Duke and Horst Brand, "Cyclical Behavior of Productivity In the Machine Tool Industry," *Monthly Labor Review,* November 1981.

The development of CNC, which essentially built computer capability into the machine tool, made NC technology more accessible to smaller firms. However, while the CNC market grew during the 1970's, major U.S. producers tended to neglect the small-firm market. This happened because the large-firm market was strong during the mid to late 1970's. Also, small firms were considered relatively unreliable customers, particularly sensitive to machine-tool market cycles and lacking in technological sophistication.

During the 1970's, the Japanese increased their share of the U.S. NC machine-tool market. They quickly dominated the U.S. market for small NC lathes and machining centers (see fig. 28). The import success of the Japanese has been attributed to several factors, including the inadequacy of domestic capacity (which has led delivery times to rise to between 1.5 and 2 years), the Japanese strategy of concentrating on selling a few products to assure competitive advantage,* and favor-

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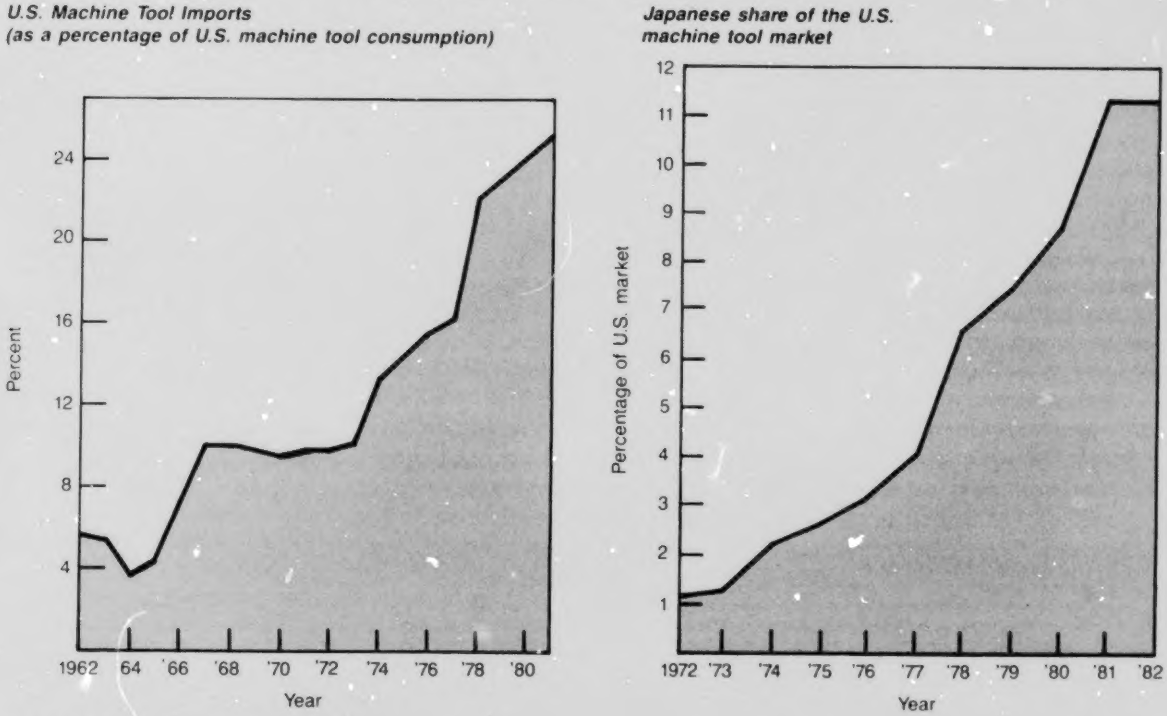
*By focusing on a few products, Japanese producers gained scale economies, allowing more flexibility in pricing.

Figure 28.—Machine Tool Import Trends



SOURCE: National Machine Tool Builders' Association able exchange rates, which gave the Japanese a price advantage relative to U.S. firms. Other factors, discussed below, include the slowness of U.S. machine-tool firms to adopt new technology and differences in U.S. and Japanese market characteristics (and related government policies).

The U.S. machine-tool industry has historically been **slow to adopt** new technology. Because of relatively low levels of capital investment, the average age of equipment used in the machine tool-producing industry has been relatively high and the level of equipment sophistication relatively low. Old equipment appears to be a factor in the poor productivity performance of the industry in the past (productivity growth in machine tools peaked in 1966, subsequently declined, and rose again in the late 1970's).[33] The machine-tool industry has tended to rely more on skilled labor than on advanced equipment in production. This pattern developed because of the complexity and low production volumes of machine tools; the prominence of small, small-batch producers with limited ability to invest in new equipment; and the high levels of financial risk in the industry.* The machine-tool business is considered financially risky because of its sensitivity to changes in the business cycle and in the buying patterns of major customer groups including DOD, other equipment producers, and makers of consumer durables. Prior to the recent pair of recessions, business declined severely for the industry in 1956-58, 1969-71, and 1974-75.

Characteristics of the U.S. NC industry may have undermined its competitiveness. Three dimensions for comparison are interfirm communication, relative specialization, and attention to small firms. According to some analysts, compared to Japanese firms, U.S. producers of machine tools, controllers, and semiconductors have not communicated well with each other. To improve the match between machine tools and controls, major machine-tool builders attempted to produce their own controllers during the 1970's; most failed to do so successfully. In contrast, Japanese producers of semiconductors, controllers, and machine tools appear to have communicated well, and they have participated in cooperative R&D and product development efforts. Cooperative efforts and communication appear to have been encouraged by the Japanese Government (see ch. 9).* These collaborations may have contributed to their rapid domination of the small machine tool market.

The different patterns of interaction among firms in the two countries are due, in part, to different industrial structures. In Japan, the major producers of machine tools and controls are highly specialized, although they are linked as "independent" subsidiaries to producers of related products. For example, the leading Japanese control builder, a monopolist, is also linked to related businesses: Fuji, a leading electronics firm, spawned Fujitsu, a leader in industrial controls, which in turn spun off Fanuc, a specialist in NC controllers. Most Japanese machine-tool companies have standardized their products to use Fanuc controls. By contrast, in the United States, GE once dominated the NC control market but lost its shares to competitors such as Allen-Bradley because it failed to keep pace with market and technological developments. (This may have happened because GE does not focus exclusively on the machine-tool market, or because of bad managerial judgment, or both.) While the Japanese pattern of specialization may have facilitated early production and use of NC, its value in more complex areas—such as machining cells or FMS—that draw on electronics and mechanics is less clear.

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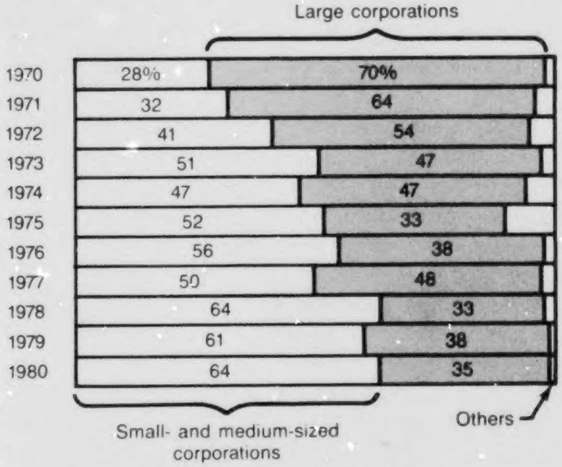
[33] John Duke and Horst Brand, "Cyclical Behavior of Productivity in the Machine Tool Industry," *Monthly Labor Review*, November 1981.

*On the other hand, some critics of the industry—in particular, the industry leaders—charge that management became overly interested in new technology. David Noble, for example, argues that the machine-tool industry has suffered from "unreasonable technical enthusiasm and a shift away from the shop floor as a repository of innovative and practical ideas toward the laboratories . . . ." David Noble, "An Outsider's View of Machine Tool Industry," *American Metal Market/Metalworking News*, Aug. 8, 1983.

*They have also been cited in recent industry appeals for U.S. Government intervention, including the 1982 petition by Houdaille to deny investment tax credits to purchasers of Japanese NC machining centers and punching machines, and the 1983 petition by the National Machine Tool Builders' Association for restriction of machine tool imports on national security grounds.

Finally, Japanese import penetration built successfully on the unmet demands of smaller firms for NC equipment. Japanese production and use of smaller NC equipment was relatively well-established before exports were significant. About two thirds of NC equipment in Japan is bought by small-and medium-sized firms (see fig. 29). Smaller firms have historically been a focus of Japanese Government support and interest (a legacy of the relatively recent transition of the Japanese economy away from an agricultural base). Unlike the U.S. Government, the Japanese Government focused its support for NC diffusion on commercial/civilian use, especially by small and medium-sized firms. Also, ties between final customers and producers appear to be stronger in Japan, another factor that may have hastened NC diffusion in Japan. The expertise gained by Japanese machine-tool builders in smaller NC installations helped them to serve the small-user niche in the U.S. market, while the increase in production volume afforded by sales to markets in two countries lowered costs.

Figure 29.—Breakdown of Japanese Numerically Controlled Machine Tool Shipments by Size of End Users (percent)



SOURCE: Japan Machine Tool Builders' Association. Reproduced in "Machine Tool Industry: The Long Road to Recovery" by Eli Lustgarten, Paine, Webber, Mitchell, Hutchins, Aug. 8, 1983.

Recent and Contemporary

The NC industry in the United States has become more competitive as declining costs have allowed more companies to produce equipment for small customers. The fact that NC machine-tool builders continue to be larger, on average, than non-NC firms is a legacy of the past, when only large firms could bear the expense and risk of NC production. Financially, the machine-tool industry as a whole has been suffering. New orders peaked in 1979 at $5.62 billion, declining 75 percent to $1.5 billion in 1982 and continuing at 1982 levels through the first half of 1983. The decline of orders has been sharper than the previous decline in 1973-75, and the reduction in capacity utilization has been aggravated by the fact that capacity had expanded in response to the late-1970's surge in demand.[34]

U.S. NC producers have been selling higher proportions of NC equipment relative to total machine-tool volume. By 1982, NC accounted for nearly 35 percent of total machine-tool shipments (see fig. 30). Producers also are broadening their product offerings to include not only NC equipment aimed at smaller users, but also machines for processing other materials such as plastics, as well as flexible manufacturing systems (FMS) which link individual machine tools and materials handling equipment and are computer-controlled.

FMS, as a cornerstone of so-called horizontal integration of production, provides a vehicle for machine-tool builders to expand their activity in selling integrated programmable automation. These systems also help machine-tool builders serve new groups of batch-production customers whose output (10 to 50 parts per hour) is less than that required to justify transfer lines but more than that which single pieces of equipment can handle. Aerospace firms appear to be particularly interested in FMS.

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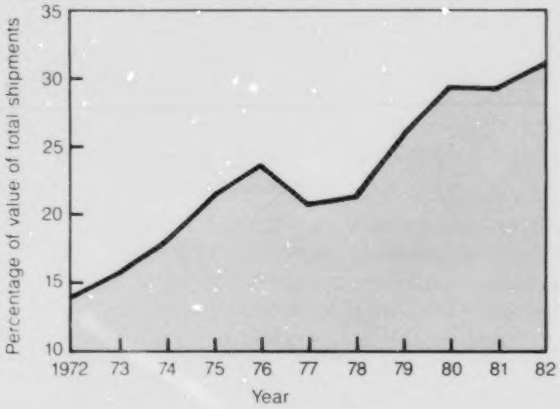
[34] Eli Lustgarten, "Machine Tool Industry: The Long Road to Recovery," status report, Paine Webber Mitchell Hutchins, Aug. 8, 1983.

Figure 30.—Value of U.S. Shipments of Numerically Controlled Machine Tools as a Percentage of Value of Total U.S. Machine Tool Shipments (for machines valued over $1,000 1972-77 and over $2,500 1978-82)



NOTE: 1982 data are for first three quarters.

SOURCE: U.S. Department of Commerce, "Current Industrial Reports, Series MQ-35W, Metalworking Machinery" (quarterly and annual summaries).

Although the market for FMSs is relatively small and existing FMSs have been largely experimental, machine-tool firms appear eager to supply FMSs and even to underprice bids.[35] The leading FMS vendor is Kearney & Trecker (part of Cross & Trecker), which has sold about half of the FMSs installed in the United States. Other vendors include Cincinnati Milacron, White-Sundstrand, Ingersoll Milling Co., Mazak Machinery Co. (Yamazaki), and Giddings & Lewis Machine Tool Co.

The association with advanced technology afforded by FMS offerings can be helpful to producers for marketing purposes. For similar reasons, some machine-tool builders (e.g., Cincinnati Milacron and Textron/Bridgeport) are beginning to sell robots. Also, U.S. firms may emphasize "high-technology" capital goods as a competitive strategy, telling customers that higher prices relative to the Japanese reflect a technology premium. Finally, support for FMS development (and purchase by aerospace firms) is provided by DOD projects promoting the design and use of integrated manufacturing systems. While FMS offers users the potential for savings in production time, direct labor, floorspace, and work-in-process inventory, the number of customers is low because existing systems are expensive, require extensive planning and support, and prove relatively difficult to operate successfully (at least at first).

Trade trends, especially imports, remain a salient feature of the contemporary NC and overall machine-tool industries. The U.S. balance of trade in machine tools became negative in 1977 and has steadily worsened. Japan is the principal source of U.S. machine tool imports. Other major import sources are West Germany, the United Kingdom, Taiwan, Switzerland, and Italy. The decline in domestic production in 1983 contributed to growth in the percentage of imports relative to 1982 levels, from 28 to about 37 percent for metalcutting machine tools and from 22 to almost 36 percent for metal forming machine tools.[36] The Japanese share of the U.S. market for some machine-tool products exceeds 50 percent. It is greatest for NC lathes and machining centers, which are the fastest growing markets in the United States and abroad.[37] Because of the recession, Japanese machine-tool exports declined significantly from their 1981 peak in 1982 and 1983.[38] Various government and trade groups are currently examining whether the Japanese have engaged in unfair competition and debating whether the machine-tool industry in the United States has a special claim to the public interest for national security reasons.*

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[35] As of late 1983, Kearney and Trecker reported about $250 million worth of proposals with high likelihood of becoming orders. "Machinery/Capital Goods Industry: Flexible Manufacturing Systems," Kidder, Peabody, & Co., Inc., Sept. 30, 1983.

[36] U.S. Department of Commerce *1984 U.S. Industrial Outlook* (Washington, D.C.: U.S. Government Printing Office) January 1984.

[37] See Eli Lustgarten, "Machine Tool Industry: The Long Road to Recovery," status report, Paine Webber Mitchell Hutchins, Aug. 8, 1983.

[38] Mark Sfiligoj, "Imports from Japan Fall," *American Metal Market/Metalworking News*, Japanese Machine Tools Supplement, July 11, 1983.

*The National Academy of Sciences, the International Trade Commission, the Department of Commerce, and Congress have actively considered machine-tool industry issues during the past 2 years.

U.S. exports have also been declining, due to worldwide recession and to longer term, noneconomic reasons. During the late 1970's, changes in foreign policy curbed shipments to Eastern Europe and the U.S.S.R., while durin the early 1980's, the nationalization and/or government-imposed consolidation of machine-tool industries in such countries as France, Spain, and the United Kingdom have effectively closed these exports markets to the United States.*

Some companies based abroad have begun to produce machine tools in the United States. Mazak (a subsidiary of the Japanese firm, Yamazaki) has established a highly automated facility in Kentucky for producing NC lathes and machining centers. Other firms, such as LeBlond-Makino, Hitachi Seiki, and Scharmann Gmbh., are only assembling foreign-designed equipment in the United States. And some foreign firms, such as Mitsubishi Heavy Industries and Toyoda Machine Works, have licensed machine designs for production by U.S. firms.

Likely Change

During the next two decades there may be a resurgence in machine-tool demand as part of a broader trend toward industrial modernization. Several analysts anticipate such a trend, since about a third of machine tools in use in the United States are at least 20 years old.[39] Indeed, recent research shows that older, midwestern plants are among the principal buyers of new machining technology.[40] The Department of Commerce has forecast relatively rapid business growth for the machine-tool industry during 1984, but it expects shipments to remain below the 1982 level.[41]

Structurally, the overall U.S. machine-tool industry is likely to continue to contract. This should happen because of the persistence of heavy financial losses during the early 1980's, because of the movement of the U.S. firms away from domestic production of hardware, and because import competition appears to have eroded U.S. market share permanently. Also, lack of experience in manufacturing systems and limited capability to develop software are likely to restrict entry into FMS and related businesses. It is possible that only the largest companies may be able to develop the extensive software and electronics expertise needed to succeed in the systems market.

While the machine-tool industry as a whole contracts, the NC share of the industry will continue to grow. This will be hastened by the anticipated rapid decline in the cost premium of NC relative to conventional machine tools. It will also reflect market withdrawal of small and medium-size firms unable to afford to modernize their products and facilities. Increasing sophistication of NC products and increased emphasis on integrating NC equipment into manufacturing systems, both of which entail an ongoing infusion of computer/electronics technology, may make the future machine-tool industry more of a "high-technology" industry than it has been. How the industry will evolve depends on several factors which bear on the competitiveness of the industry, such as new product and market (segment) development and increased efficiency.

Major machine-tool builders have begun modernizing their own facilities, resorting in many cases to greater use of programmable automation. For example, the Wickes Machine Tool Group, Inc., has arranged to purchase a CAD system to help it compete with larger firms; Kearney and Trecker (Cross & Trecker) is installing one of its own FMSs; Brown & Sharpe Manufacturing Co. uses CAD to design new products and to translate plans for 3-D products into 2-D patterns for sheet metal processing; and Ingersoll Milling Machine Co. has used CAD to develop a new FMS.[42] But

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*The French program began in December 1981 and aims to double French machine-tool production, raising it to about $995 million by 1986. One of the program's goals is to halve the 60 percent import penetration of 1980 by the middle of the decade. *American Metal Market/Metalworking News*, July 25, 1983.

[39] "The 13th American Machinist Inventory of Metalworking Equipment 1983," *American Machinist*, November 1983.

[40] John Rees, et al., "The Adoption of New Technology in the American Machinery Industry," Occasional Paper No. 71, Maxwell School of Citizenship and Public Affairs, Syracuse University, August 1983.

[41] "Commerce Department Foresees Metalworking Gains," *American Metal Market/Metalworking News*, Jan. 2, 1984.

[42] *American Metal Market/Metalworking News*, various issues.

the costs of modernizing in the context of strong import competition and a sluggish market may lead other firms to withdraw from the market. Machine-tool builders have also contemplated cooperative research ventures, and several companies have recently built new research facilities. For example, Cincinnati Milacron, Inc., has completed a new research center; Ex-Cell-O has a new technology center; Monarch Machine Tool is forming a new engineering development lab; and South Bend Lathe is adding a new engineering group for its research division.[43]

Rather than improve domestic plant and equipment, there is already evidence of a growing reliance by U.S. firms on foreign companies, or on their own production facilities abroad, for the hardware they sell. As one machine-tool industry executive explained to the International Trade Commission:

> It is essential to distinguish between the future prosperity of American companies that trade in machine tools and the future prosperity of the domestic machine tool building industry. Cross & Trecker is committed to the business of machine tools, but it is not committed to build in the United States all or any specific portion of the machine tools it sells here.[44]

Bendix, before deciding early in 1984 to divest its industrial automation operations, planned to introduce new products while shifting the production of other products (small CNC lathes and chuckers) to Japan, where it participated in a joint venture with Murata Machinery Co. Also, it had invested in the Italian firm Comau, which could have provided it with hardware; and it had arranged to be the exclusive distributor of Toyoda Machine Works NC machine tools in the United States and Canada. Acme-Cleveland and Cross & Trecker have forged agreements with foreign firms to supply equipment to replace or add to products already made and sold in the United States. Another firm, Sulzer, has recently chosen to enter the U.S. market by selling Italian equipment under license. On the other hand, Cincinnati Milacron officials have stated that they plan to continue to produce commodity machinery, in part because advances in machine-tool technology make control over the design of both hardware and controls important.[45] Yet some of their equipment may be produced in their European facilities. Interestingly, the willingness of leading U.S. machine-tool builders to move offshore suggests that they do not believe that PA technology alone would sufficiently lower their own production costs.

Three principal areas of new product development that may benefit the domestic industry are products for processing nonmetal materials, products aimed at smaller users, and manufacturing integration. Products for processing nonmetal materials include machinery for processing plastics, especially composite materials (used increasingly by the aerospace industry). The growing substitution of plastics for metals in the aircraft, motor vehicle, and appliance industries, among others, is feeding long-term growth in plastics machinery sales. Cincinnati Milacron, for example, not only makes computer-controlled plastics molding machinery but offers robotic cells for plastics production and equipment for producing and inspecting items made with composites. Other equipment may be aimed at processing ceramics, used increasingly by the auto and aerospace industries, in particular.

There are several reasons why machine-tool firms may aim to serve smaller customers. One is that the huge automotive and commercial aerospace purchases of the late 1970's are not likely to be repeated; thus, defense spending and small firms may become key forces in the market.* An argument for growth in small-user demand is increased competition among smaller metalworking firms for business, a trend indicated both by OTA case studies and by other evidence. The benefits of NC in terms of improved production reliability, better cost estimation, and faster production time may become increasingly attractive to smaller users facing high competition for machining work. On the other hand, since small manufacturers were the principal victims of the past recessions, their spending capacity is uncertain.

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[43] *American Metal Market/Metalworking News*, June 12, 1983; NMTBA Pet. Supp.

[44] Rosanne Brooks, "Tool Builders Consider Offshore Sites," *American Metal Market/Metalworking News*, July 4, 1983.

[45] Bruce Vernyi, "Machine Builders Look to New Technology Products: Some Concede Standard Lines to Foreign Firms," *American Metal Market/Metalworking News*, June 13, 1983.

*Note that offset, coproduction, and other agreements are increasing the foreign production component of U.S. civil and military aircraft, a trend that adversely affects U.S. parts suppliers and presumably constrains U.S. machinery demand.

Other motivations include the possibility of tighter links between prime manufacturers and subcontractors in the automobile and aerospace industries. These links are associated with such inventory-control strategies as the just-in-time system, which tends to be accompanied by single-sourcing of supplies, and with the spread of programmable automation itself, which encourages direct computer links between manufacturers and suppliers. The National Tooling and Machining Association (NTMA), for example, has arranged seminars between major auto producers and metalworking suppliers to facilitate the transition to PA. The possibility of closer links with their customers may spur metalworking and other suppliers to modernize their facilities; in effect, such a requirement may be imposed on them.

Though smaller users offer a potential for market expansion, the primary U.S. competitive strength continues to be in larger, more complex systems. This is one reason why machine-tool builders may seek to procure smaller products from foreign sources. Lodge and Shipley, for example, has begun to market small CNC lathes from Italy. Strength in large systems is also a reason why major NC producers are likely to further emphasize integrated manufacturing, through supply of manufacturing cells, FMS, and other integrated systems, and through the production of robots. Cross & Trecker, for example, recently formed a division to produce automated materials-handling devices. It also acquired Bendix' operations for industrial controls, machine tools, and robots.

Machine-tool builders may continue to expand into robot production because, among other reasons, robots can complement machine tools or accessories (e.g., loaders, changers) within FMS or other settings. Also, transfer lines and other special machine-tool products are expected to be more flexible and capable of producing small lots and component families economically. They will include advanced computer control and monitoring, sensors, and automated functions for stock delivery, gauging, loading, and removal of broken tools.[46]

While NC producers may supply integrated systems by making key components and software themselves, it is also possible that they may adopt a turnkey approach, assembling components made by a variety of companies. As NC machine-tool builders become better able to match machine tools with controls, and as users seek to standardize the controls they use, machine-tool builders may become increasingly willing and able to offer their equipment with a variety of options for controls.[47] Turnkey operation is also more likely if NC firms continue to diminish their domestic production and focus more on machine-tool distribution. On the other hand, machine-tool builders may establish links with such firms as IBM, GE, or Westinghouse, supplying hardware which those firms would package for sale with engineering services, controls, and software.

Control makers themselves are already involved in the integration field. Allen-Bradley, for example, offers an "area control" system to integrate management and operation functions. It is working with 3M and Western Digital to develop a broadband local area network that would allow a wide range of manufacturing devices to communicate. Both systems would accommodate equipment from different vendors, making integration more accessible to users.

Regardless of how much hardware NC suppliers build themselves, their nonproduction activities will continue to increase. This trend is due in part to the large need for support activities associated with the design and implementation of complex systems like FMS. Such systems require extended (2 to 5 years) planning by users, whether for retrofit or new-facility installations. NC producers have begun to establish service units that advise customers in the planning for and design of automated systems. For example, several firms, including Cincinnati Milacron and Allen-Bradley, now have automation consulting units.

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[46] Al Wrigley, "Versatile Transfer Lines," *American Metal Market/Metalworking News,* Aug. 15, 1983. Lauri Giesen, "Transfer Line Design is Changing Rapidly," *American Metal Market/Metalworking News,* Aug. 15, 1983.

[47] See, for example, "Bridgeport Shows Tools," *American Metal Market/Metalworking News,* Sept. 20, 1982.

Future trade trends in the NC industry are difficult to predict, although the status of the U.S. market as the largest machine-tool market in the world (followed by the U.S.S.R., West Germany, and Japan) suggests that foreign competition will persist. Key factors bearing on U.S.-Japan competition are the prospects for protectionist action by the United States and of voluntary export curbs initiated by the Japanese, although the Japanese already have large inventories positioned in the United States. More generally, other factors affecting trade patterns include the development of foreign markets, and changes in U.S. customer demand. For example, Ford's shift from turning to milling of crankshafts offers new opportunities to foreign machine-tool firms, which already produce for this application (unlike U.S. firms).[48] Other changes in customer products and processes may also affect the competitive balance. Finally, competition in NC will depend on the relative similarity of national preferences. For example, Japanese vendors and users appear to prefer relatively simple FMSs, while U.S. companies appear to prefer more sophisticated systems.[49] If NC sales, including FMS, become increasingly oriented toward integrated systems, the traditional U.S. strength in software and systems technologies may prove to be an enduring advantage.

Robots

History

The role of entrepreneurs, and the absence of a major government role, distinguish the early development of the robotics industry from that of other PA technologies. After Unimation installed the first commercial robot in 1961 in the auto industry, sales were negligible for about a decade. With a virtual monopoly, Unimation had sold only 200 robots by 1970.[50] One other firm, Versatran (now part of Prab Robots), also sold a few robots during that first decade. Several other firms investigated robotics technology during the 1960's without entering the market.

By the mid-1970's, robot sales in the United States had risen to about $15 million. Cincinnati Milacron and DeVilbiss (machine-tool builders), Autoplace (Copperweld Robotics, until sold in early 1984), Prab Conveyors (a materials handling equipment maker, which bought out Versatran and became Prab Robots), and Swedish-owned ASEA had become significant vendors, although Unimation remained the leader. Cincinnati Milacron and ASEA developed their own robots, but they also licensed technology from Unimation,[51] while DeVilbiss sold robots licensed from Trallffa (of Norway). The automobile industry was the principal customer, buying robots for applications such as spot welding and spray painting. Figure 31 shows market growth trends.

Major investment programs by automobile manufacturers led the growth in demand for robots in the late 1970's. Although the auto industry was already heavily automated, volatile consumer demand and variable production runs created a growing problem of premature obsolescence of plant and equipment. These factors, plus foreign competition, generated pressure to reduce costs as well as increase flexibility and quality in production.

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[48] Jack Thornton, "Ford Engine Plant to Mill Rather Than Turn Cranks," *American Metal Market/Metalworking News*, Sept. 20, 1982.

[49] "In FMS, Simplicity Governs," *American Metal Market-working News*, Japanese Machine Tool Supplement, July 11, 1983.

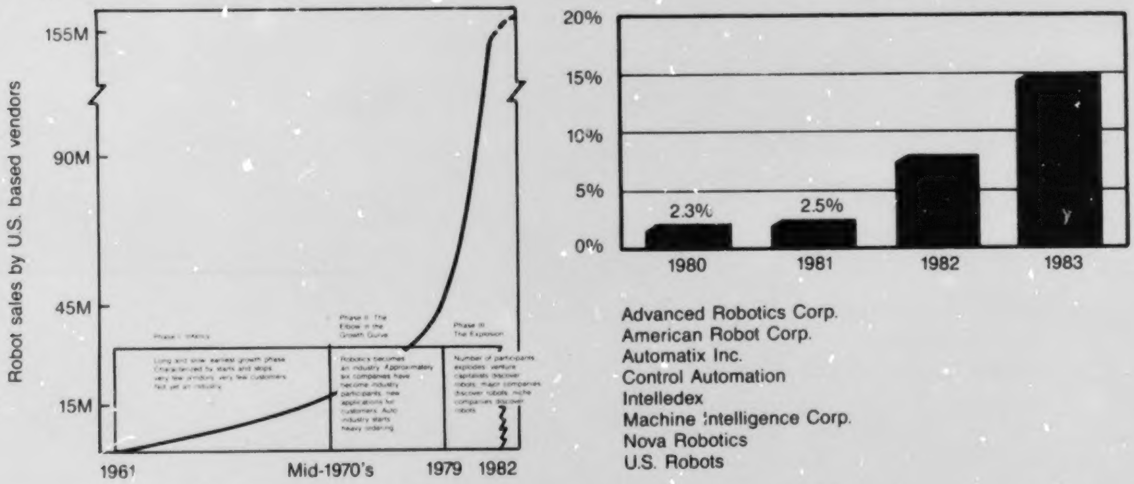
[50] "Tackling the Prejudice Against Robots," *Business Week*, Apr. 26, 1976.

[51] "Robot Makers Still Waiting for Promised Big Markets," *Electronic Business*, October 1980.

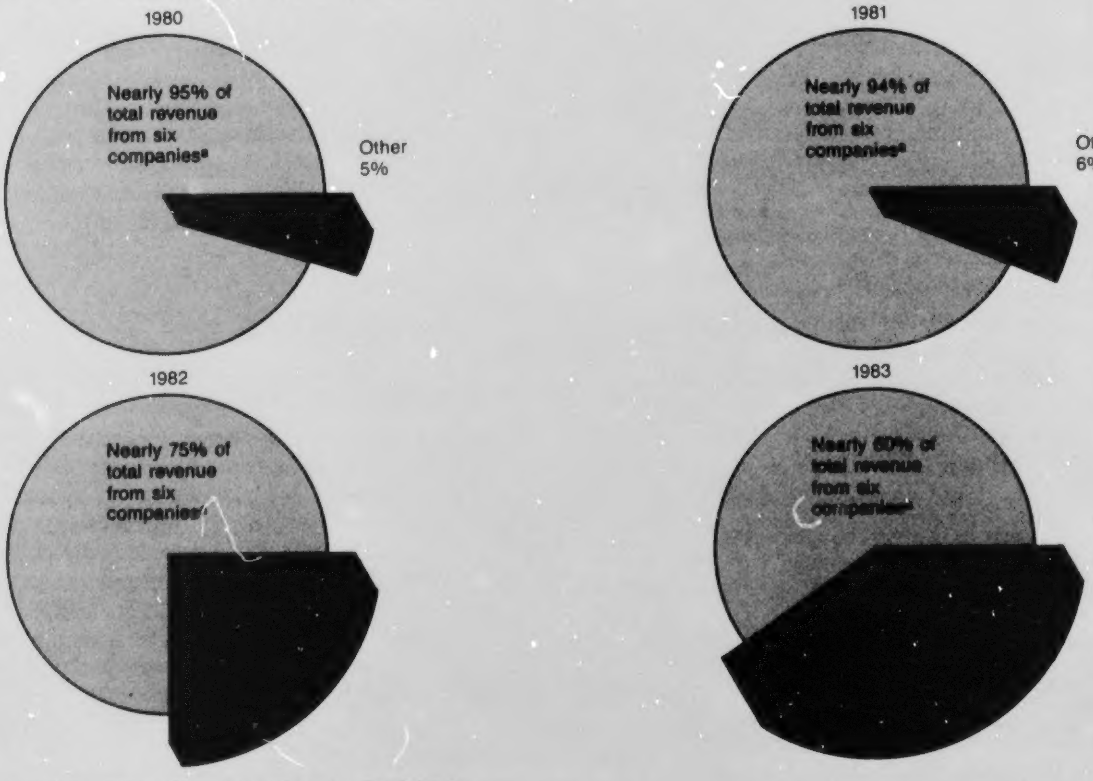
Figure 31.—Robot Market Trends

The phases of the robot industry

Market share: startup companies only; 1980-83



Changes in market share composition, 1980-83



[a] Unimation, Cincinnati Milacron, DeVilbiss, Asea Inc., Prab Robots Inc., Copperweld Robotics

SOURCE: Prudential-Bache Securities, Inc.

Substitution for less flexible equipment, and the reduction of labor costs, were both major motivations for automotive use of robots. By late 1980, 1,400, or nearly half of the 3,200 robots Unimation had installed, were for spot-welding applications.[52]

The potential market for robots in the aerospace and electronics industries was also explored during the 1970's. The aerospace industry, unlike the automobile industry, contained relatively few obvious applications, because aircraft are very high-precision products produced in small batches; early robots tended to be insufficiently precise and relatively expensive to adapt for each use. During the mid to late 1970's, DOD programs (e.g., ICAM) aimed at improving defense procurement motivated the evaluation, perfection, and adoption of robots by large aerospace firms working in conjunction with government and university researchers (see ch. 8). Although DOD technology-diffusion programs also evaluated the use of robots for electronics applications, the electronics industry was largely responsible for developing its own early applications. Firms such as Texas Instruments and IBM developed robots and applications in such broad areas as materials handling and simple assembly.

Foreign firms have participated in robot markets since the 1960's. The Japanese industry grew bigger and at a faster rate than the U.S. industry.* This happened in part because the Japanese Government encouraged robot use by small and medium-sized firms, through such measures as a robot leasing program (see ch. 9). The typically close links between major Japanese manufacturers and their suppliers also served to promote growth in smaller firm use of robots. In 1968, Kawasaki licensed robot technology from Unimation, becoming the first and leading Japanese producer. Japanese vendors proliferated, as companies that had earlier built robots for their own use (e.g., Pentel, Seiko) entered the external domestic market. Across a relatively broad range of industries and firm sizes, Japanese firms adopted robots and other forms of automation relatively quickly because of a shortage of skilled, entry-level labor in Japanese manufacturing industries, particularly those industries in which production work was considered onerous.

During and since the 1970's, other major producers of robots have appeared in various European countries. Trallfa of Norway is a major producer of spraying robots; its technology is licensed to DeVilbiss. ASEA of Sweden is a major producer of arc-welding robots; it has a U.S. subsidiary and operates in several other countries. Vendors based in France, Italy, West Germany, the United Kingdom, and other European countries, where indigenous industries tended to develop around the local auto industries, also began to sell robots in the United States.

Recent/Contemporary

The robot market has reportedly grown to exceed $200 million in sales in the United States, and perhaps $1 billion worldwide.* The robot business, however, remains unprofitable—the growth of sales has been described by Laura Conigliaro, a financial analyst of the robot industry, as "profitless prosperity." One industry participant recently compared the estimated $200 million in 1982 sales with about $500 million in costs.[53] The ITC concluded from its industry survey that robot vendors lost money through the 1979-83 period.[54] There are several reasons for this situation, which stems from the immaturity of the market. Vendors are trying to position themselves in a nascent market, they often deliver products they have yet to perfect, and users often require extremely high levels of service and support to make an application successful. Consequently, high costs for marketing, applications development, support, and production of special tooling erode profits from robot sales. Table 58 lists shipment estimates from ITC (note that since 1980, shipments have included a significant fraction of robots for instructional purposes).[55]

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[52] Ibid.

*Japanese robot production (not necessarily restricted to U.S. robot definition) grew from 200 units ($1.6 million) in 1968 to 8,600 units ($8.7 million) in 1977 and 19,387 units ($314 million) in 1980. "Japanese Production Runs Limit Robotic Investments," *Aviation Week and Space Technology*, Aug. 2, 1982.

*Industry analysts estimate that 1982 sales were $200 Million, while 1983 sales are believed to approach $240 Million. The International Trade Commission estimated that 1982 U.S. sales by domestic firms alone were under $140 million. Note that it is hard to measure sales and profits because most vendors are privately held or are small parts of large companies that do not break out sales data. Therefore, industry analysts generally seek to count units sold and estimate sales based on average price. Average price, however, will vary depending on customer preferences for accessories and other items accompanying the sale of the basic manipulator.

[53] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

Among users, the auto industry continues to dominate; other major users include aerospace, electronics, machinery, foundries, and miscellaneous light manufacturing (see table 59). Among applications, spot welding, machine loading, spray painting, and materials handling are most prevalent, although arc welding, inspection, and assembly applications are becoming more common, in part because of a growth in sensor technology, especially vision systems, for robots. From 70 to 80 percent of robots in the auto industry are used for welding.

Because the robot market holds the prospect of eventual profits, U.S. robot vendors have proliferated since 1980. While Unimation and Cincinnati Milacron still lead the market, they face competition from a diverse set of market entrants, including small, innovative startup firms and large, diversified multinationals. There are about 100 U.S. vendors, compared with about 250 in Japan and several dozen in Europe.[56] * The market includes both full-line firms and niche firms. The strongest competitors offer a range of products. In addition to robot assemblers, there are other firms concen-

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[54] "Competitive Position of U.S. Producers of Robotics in Domestic and World Markets," U.S. International Trade Commission, Publication 1475, December 1983.

[55] Ibid.

[56] See, for example: Laura Conigliaro, "Trends in the Robot Industry (Revisited): Where are We Now?" *13th International Symposium on Industrial Robots and Robots 7*, conference proceedings, Robotics International of SME, Apr. 17-21, 1983.

*Also, there are at least 30 Japanese firms that produce robots only for themselves and their shareholders. Paul Aron, "The Robot Scene in Japan: An Update," Paul Aron Report No. 26, Daiwa Securities America, Inc., Sept. 7, 1983. It is not clear how many U.S. firms produce for their own use, although IBM and Texas Instruments are examples of firms believed to do so. Square D, for example, is an electrical equipment maker that bought a young robotics firm, U.S. Robots, Inc., (which produces "Maker" robots) to obtain robots for its own small-part production. The ITC concluded from its industry survey that only 6% of shipments were intracompany (captive). The prevalence of user-producers in Japan accounts for the greater number of special-purpose robots in Japan.

Table 58.—Robots: U.S. Producer's Domestic Shipments, by Types, 1979-83

Type	1979	1980	1981	1982	1983[a]
	Quantity (units)				
Spot welders	155	344	644	434	372
Arc welders	28	52	57	91	196
Coaters	0	0	26	156	153
Assemblers and material handlers[b]	114	153	259	550	1,025
Metalworking apparatus	4	7	10	16	15
Loaders/unloaders	79	111	167	163	188
Others[c]	63	141	344	697	717
Total	443	808	1,507	2,107	2,666
	Value (1,000 dollars)				
Total[d]	19,168	43,293	90,076	122,523	134,916
	Unit value				
Average	$ 43,267	$ 53,580	$ 59,772	$ 58,150	$ 50,606

[a] Data for 1983 are based on projections provided by U.S. producers

[b] Data are combined to prevent disclosure

[c] Includes small, instructional and educational devices

[d] Data by types are not available

SOURCE: Compiled from data submitted in response to questionnaires of the U.S. International Trade Commission

Table 59.—U.S. Robot Population by Application and Industry, End of 1982

	Auto	Foundry	Nonmetals light Manufacturer	Electrical, electronics	Heavy equpment	Aerospace	Total
Welding	1[a]				1		2200 (35%)
Material handling		1	1	1			1550 (25%)
Machine loading	2	2			2		1250 (20%)
Spray painting, finishing	3		2	3	3	1	600 (10%)
Assembly				2		2	200 (3%)
Machining							100 (2%)
Other							300 (5%)
Total	2500 (40%)	1250 (20%)	1050 (17%)	700 (11%)	600 (10%)	100 (2%)	6200 (100%)

[a] About 70 to 80 percent of robots in auto industry are used for welding.

SOURCE: Tech Tran Corp.

trating on ancillary products such as end-of-arm tooling, motors, and other components for robots. Finally, not all vendors produce their wares: probably only about 50 U.S. firms actually produce robots.[57] Competition is intense, and some firms have already exited the market (e.g., Black & Decker, Kulicke & Soffa).[58] Copperweld Corp. left the robot market after recent losses on robotics systems and vision products, although it was considered the largest U.S. maker of small robots when it entered the market in 1979 (via acquisition). Similarly, Nordson Corp. is planning to divest the robotics division it formed in 1980.

Entry into the market has occurred through licensing of foreign technology, mergers, and acquisitions, as well as through new-product development. GE, for example, entered in 1981 by licensing Italian and Japanese-designed robots. GCA and Automatix are among the many companies that distribute Japanese robots under their own names, and at least one American firm has licensed a Scottish-designed robot.[59] * Cross-fertilization, through licensing, outsourcing, joint ventures, or other means, is a key feature of this market (see discussion below). Several vendors even offer robots using the same basic manipulators.[60] The prevalence of cooperative efforts is not surprising given the fact that developing a prototype robot alone costs upwards of $1 million, while the full costs of market entry are closer to $15 million to $20 million. The costs of entering and operating the business are even higher.

Several firms have been financed by venture capital, although external financing is believed to be less available now than it was just a few years ago. Intelledex, for example, was founded in 1981 by former Hewlett-Packard employees using venture capital; it is developing sophisticated robots with vision for electronics assembly. Control Automation, founded at about the same time by former Western Electric personnel and funded by venture capital, also aims to serve the electronics assembly market. As these examples suggest, several new firms draw on computer backgrounds or emphasize electronics applications; this contrasts with the more mechanical orientation of most of the early vendors.

Robot producers supply robots as stand-alone devices with basic systems engineering, as custom-turnkey systems, or as modular-turnkey systems. As in other PA markets, turnkey firms combine robotics components made by others with controls, software, and tooling tailored to meet the requirements of specific applications. Robot systems are available based either narrowly on a robot or more broadly on a manufacturing cell served by a robot (e.g., as a machine tender/loader). Automatix, for example, was founded as a vision company that imported Japanese manipulators and sold them with vision systems of its own design. It recently introduced a line of robotic assembly cells with vision systems that can be combined into a larger assembly system. Robot systems with vision capabilities have grown more common; 25 to 30 percent of machine vision systems sold are sold with robots.[61]

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[57] See "Competitive Position of U.S. Producers of Robotics in Domestic and World Markets," U.S. International Trade Commission, Publication 1475, December 1983.

[58] Kulicke & Soffa had formed a new division and invested over $1 million in robotics research over a 2-year period. See "Recession Even Hits Robots," *The New York Times*, Jan. 12, 1983.

[59] "Cameron Gets Robot License," *American Metal Market/Metalworking News*, June 6, 1983.

*Bendix, for example, distributed three Yaskawa robot systems in the Western Hemisphere under the Bendix name and provided support and services. *Wall Street Journal*, Dec. 7, 1982.

[60] "Robotics: Too Many Firms for the Market?" *The Journal of Commerce*, Apr. 25, 1983.

Both large, diversified vendors such as IBM, GE, and Westinghouse, and smaller ones such as GCA and Cybotech, offer to integrate robots or robotic systems with a variety of other types of production automation. Several vendors, such as GCA and IBM, offer to link CAD units to robots, allowing robots to be programed and applications to be simulated through CAD systems. The strategy of some of these vendors is to treat robots as additional terminals in larger, computer-based systems. Such systems can eliminate the need for separate robot programing and related support activities.

While the manipulator (the basic robot hardware) accounts for over half the total cost of installing a robot (see fig. 32) the increased attention to controls, software, and service accompanying the trend toward treating robots as part of systems is reducing the role of hardware in the robot business. As one industry participant observed:

> To me, the robot system is probably fifty percent controls and software and another twenty-five percent peripheral application and tooling and staging. And only twenty-five percent of it is the basic robotic mechanism that you see.[62]

Thus, at the Robot 7 exposition, for example, Cincinnati Milacron demonstrated only three robot models and one control unit, available with different options. The hardware was standardized, but different customer needs could be met by varying the software.

For both simple and complex applications, pre- and post-sale support and service are increasingly considered essential by both vendors and users. One indicator that service and support have been inadequate is the fact that buyers have occasionally abandoned robots, something that has not been a problem for CAD systems and other types of programmable automation. A lot of pre-sale support—planning, training, facilities preparation, etc.—is often needed, for a couple of reasons in particular: Robots have yet to be viewed as the only alternative for certain tasks (unlike, say, lathes); and there are no single, correct approaches to applying robots in given situations. Because robot technology is still developing, and because users often adopt their first robots as a preliminary to broader process change, post-sale support—e.g., software updates, service contracts—is also important. While early robot vendors (e.g., Unimation, Prab, and Cincinnati Milacron) initially focused on manipulator production, growing competition has made service increasingly important to the business.

Some vendors have altered their pricing patterns in recognition of this situation, although pricing strategies appear to vary too much to permit meaningful inferences. For example, rather than offer a $100,000 robot, a vendor may now offer the "robot" for $30,000 and support/service for $70,000. Indeed, some industry analysts have somewhat cynically observed that selling robots is analogous to giving away (virtually) razors and profiting from

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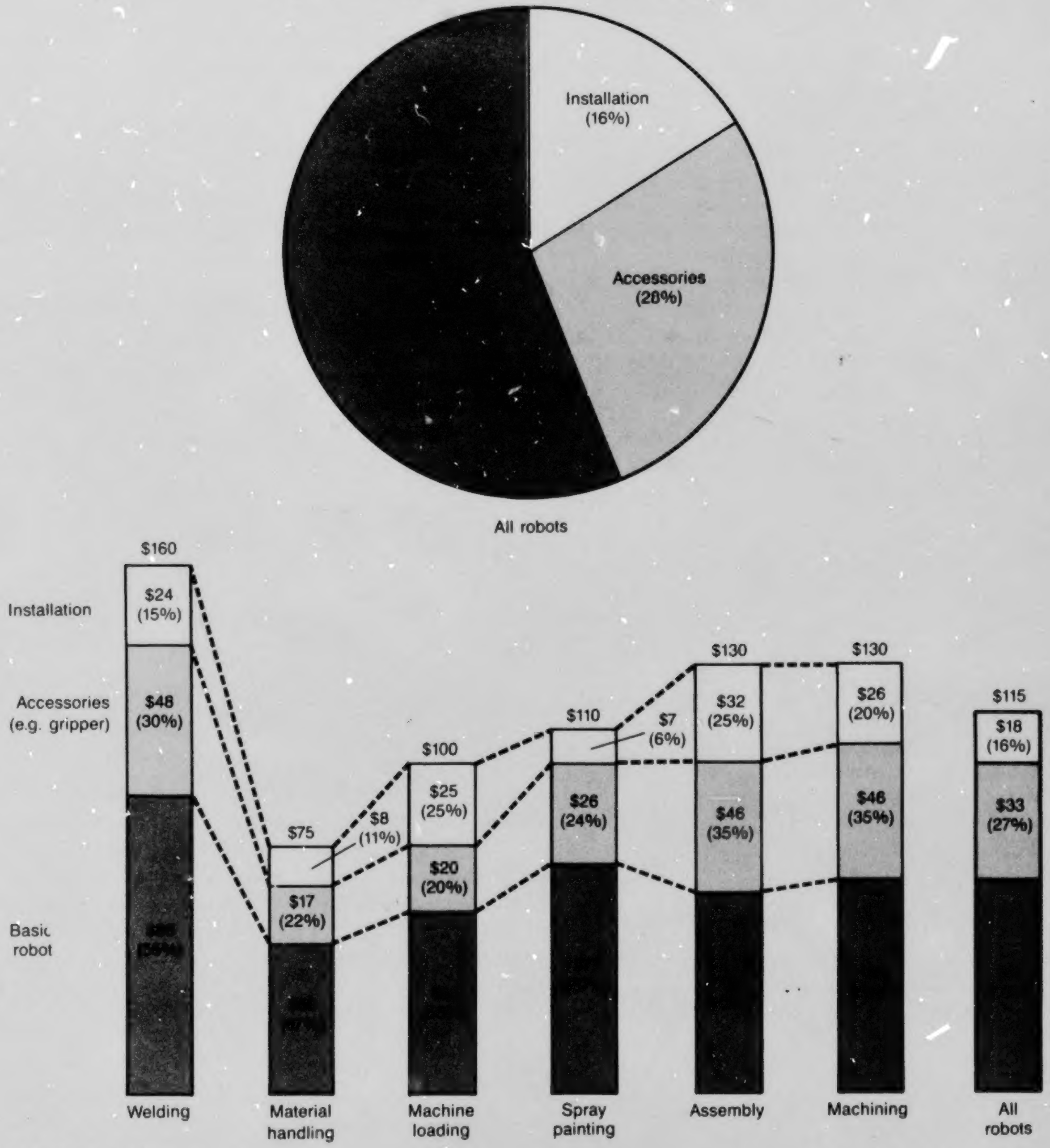
[61] See Robert N. Stauffer, "Sensors: 50,000 Machine Vision Systems Seen by 1992," *Robotics Today*, April 1983. Tech Tran estimates that, as of early 1983, only 400 to 500 machine vision systems were in use, but up to 50,000 systems may be used by 1993. Machine vision systems currently cost $25,000 to $30,000 but may cost less than $10,000 by 1993.

•The vision system market is believed to contain over 100 suppliers. Vision system sales have been estimated at $18 million to $25 million in 1982, and forecast to grow rapidly during the mid to late 1980's.

[62] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

Figure 32.—Typical Robot System Cost Breakdown



SOURCE Tech Tran Corp

the sale of razor blades: the money is in the follow-on sales of complementary products. Another interpretation is that vendors have yet to offer products that users really want. In particular, there is some evidence that users want simpler systems.[63]

Large and small system-oriented vendors have responded to perceived needs for service by enlarging their service capacity, and by adding systems-planning consulting units. For example, IBM has a Robotics Assembly Institute; GCA has two demonstration centers; Prab has a systems engineering unit; and GE has a few robot applications centers. In addition, third-party robotics consulting/service firms have emerged. These include Productivity Systems, Inc. (Mich.); Ceeris International, Inc. (Conn.); Franklin Institute Research Laboratories, Inc. (Pa.); Scientific Applications, Inc. (Va.); and Automation Systems/American Technologies (N.J.). **Third-party or nonmanufacturing firms have a place in the robotics business, as in the CAD business, because the hardware is less important than the applications engineering, software development, and other aspects that combine in an application** (see CIM section below). These firms may also become more prominent because the amount of capital available for new-start manufacturers is shrinking, and consulting is less expensive to launch than manufacturing.

The robot market continues to be strongly international, although it is believed that robot imports comprise less than 10 percent of the market.[64] This compares with a 25 to 30 percent import penetration for automobiles. According to ITC, U.S. imports of complete robots grew in value from $3.8 million in 1979 to $15.1 million in 1982 and may have grown to $28.9 million in 1983. Imports of robot parts and subassemblies grew from $126,000 in 1979 to $6.7 million in 1982 and may have grown to $15.2 million in 1983. According to Paul Aron of Daiwa Securities America, Inc., 425 units valued at about $11.4 million were imported in 1982, of which 59 percent came from Japan, compared with a total of $195 million in domestic production.[65]

Japan has been the principal source of robot imports; Sweden and Norway follow, together accounting for less than half of the value of Japanese imports. Sweden follows Japan and the United States as the third largest robot producer. Its principal robot manufacturer, ASEA, is a leading, maker of industrial machinery. ASEA produces about half of Sweden's robot output. The remaining portion of imports (about 20 percent by value, 9 percent by volume) comes from West Germany, Italy, and the United Kingdom. These countries primarily supply robots to the United States through resale agreements. Five firms produce most of West Germany's robot output. The two leading German firms are Volkswagen Werk and Kuka.[66] Several foreign firms serve the U.S. market by specializing in niches (e.g., ASEA, Yaskawa, and Hitachi in arc welding), and most others serve the low end of the market.

U.S. robot makers also export, principally to European countries. ITC estimates that U.S. robot exports grew from $8.9 million in 1979 to $20.3 million in 1982 and may have grown to $33.7 million in 1983, accounting for 20 percent of the shipments.[67]

A principal difference between foreign and domestic firms, until recently, has been the prevalence of user-producers among foreign firms. The greater experience of foreign firms (particularly Japanese firms) with robotic applications has been an important selling point. Also, the larger market in Japan helps to lower the cost of Japanese robots exported to the United States. And "the Japanese also are willing to make use of less sophisticated robots rather than wait for the most perfect design. . . . In Japan, the stress is constantly on the application."[68]

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[63] See, for example: Frank Cogan, "Some Robots Being Simplified to Attract Users," *American Metal Market/Metalworking News*, Sept. 13, 1982.

[64] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

[65] Paul Aron, "The Robot Scene in Japan: An Update," Paul Aron Report No. 26, Daiwa Securities America, Inc., Sept. 7, 1983.

[66] "Competitive Position of U.S. Producers of Robotics in Domestic and World Markets," U.S. International Trade Commission, Publication 1475, December 1983.

[67] "Competitive Position of U.S. Producers of Robotics in Domestic and World Markets," U.S. International Trade Commission, Publication 1475, December 1983.

The international dimensions of the robot industry are complicated by the prevalence of captive imports, licensing (often involving the manufacture abroad of key hardware), and joint ventures. Licensing is a particularly attractive vehicle for foreign firms wishing to enter a remote market because it eliminates the need for setting up a new distribution system; it appeals to the licensee, on the other hand, as a quick and easy means of entering a new market. R&D needs are lower, as are production costs. Many U.S. vendors, from large, diversified firms (e.g., IBM, GE) to smaller, innovative firms (e.g., GCA, Automatix), license manipulators, especially from Japan* (see table 60). As Phillipe Villers, President of Automatix, recently noted:

> If you are going to produce something in much lower volumes than a competitor, then you had better be able to command a premium for some innovative aspects . . . Now, in robotic arms as distinguished from the robot as a whole, that is a relatively mature art, and the opportunity for commanding a tremendous premium for a bettter arm is somewhat limited. At the present time, the leading Japanese manufacturers are producing arms in the thousands per year in a number of cases. For manufacturers here to compete in arms while producing ten times less of that device, the laws of economics says that you can't produce it as cheaply . . . In the controls area it's not the same.[69]

Finally, there are a growing number of international joint ventures, although these remain less common than licensing agreements. For example, Renault of France and Ransburg of the United States formed Cybotech in the late 1970's. A new joint venture, GMF Robotics, paired a major Japanese producer, Fanuc Ltd., with a major U.S. user, GM. Although its

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[68] Paul Aron, "How to Play Catchup in Robotics," *Electronics*, June 16, 1983.

*Other countries also supply robot hardware. For example, Steelweld Robotic Systems (United Technologies) sells robot systems using Niko robots made in West Germany and accessories and peripheral equipment made in the United States. *Automotive News*, Sept. 26, 1983.

[69] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

Table 60.—Some Agreements Existing Between U.S. and Foreign Robotics Producers

From	Type of agreement	To
DEA (Italy)	License and marketing	General Electric Co.
Volkswagen (West Germany)	License and marketing	General Electric Co.
Hitachi Ltd. (Japan)	License and marketing	General Electric Co.
Fujitsu Fanuc (Japan)[a]	Joint venture	General Motors Corp.
Unimation	License	Kawasaki Heavy Industries (Japan)
Unimation	License	Nokia (Finalnd)
Prab Robots, Inc.	Manufacturing	Fabrique Nationale (Belgium)
Prab Robots, Inc.	Manufacturing	Murata Machinery (Japan)
Prab Robots, Inc.	Manufacturing	Canadian English Co. (Canada)
Trallfa (Norway)	License	DeVilbiss Co.
Renault (France)[a]	Joint venture	Ransburg
Yaskawa Electric (Japan)	Marketing	Hobart Brothers
Yaskawa Electric (Japan)[a]	Technology exchange	Machine Intelligence Corp.
Sankyo Seiki (Japan)	Purchase	IBM
Komatsu (Japan)	License and marketing	Westinghouse Electric
Mitsubishi Electric (Japan)	License and marketing	Westinghouse Electric
Olivetti (Italy)	License and marketing	Westinghouse Electric
Basfer (Italy)	License and marketing	Nordson
Dainichi Kiko (Japan)	Marketing	GCA
Hitachi Ltd. (Japan)	Marketing	Automatix
Nachi Fujikoshi (Japan)	License	Advanced Robotics Corp.
Nimak (West Germany)	License	United Technologies
ASEA (Sweden)	Subsidiary	ASEA, Inc.
Cincinnati Milacron	Manufacturing	Dainichi Kiko (Japan)

[a] Information and technology flow in both directions.

SOURCE: Compiled from various sources by the staff of the U.S. International Trade Commission.

management claims to aim for no more than 50 percent of sales for automotive application, GMF appears to be gaining a major share of GM's robot business. GM's new Buick complex in Flint, Mich., for example, will include 103 robots—all from GMF.[70]

International joint ventures are also a factor in foreign markets. For example, Cincinnati Milacron and Utsumi Machinery Co. (Japan) will produce robots in Japan this year for sale in Asia and Australia. Cincinnati Milacron's Japanese subsidiary will assemble the robots from manipulators made by Utsumi and Cincinnati Milacron controllers made in the United States. Cincinnati Milacron claims that building the manipulators in Japan will cost about 20 percent less than building them in the United States.[71] Lower production costs reflect, in part, the exchange rate, as well as higher production volumes in Japan.

Likely Change

Estimates of the 1990 U.S. robot population generally range from 50,000 to 150,000, or a 6- to 18-fold increase relative to today. Sales forecasts for 1990 typically range from $1 billion to $2 billion. Clearly, changes of these magnitudes are uncertain; they depend, in particular, on a strong economy. A "shakeout" in the robot industry, with the number of vendors falling at the same time sales are growing, is widely anticipated within the industry and among analysts. Because the nature of production costs, the rate of technology change, and the growth of the market are all uncertain, there is controversy as to the prospects of new v. old firms, or large v. small firms (see table 61). During a recent forum for industry participants, the problem was underscored when representatives of several small robot manufacturers expressed their desire to be the "IBM of robotics." Because both large and small firms have strengths, and because the market is expected to broaden, it is likely that the industry will support both large, "supermarket" suppliers of automation and smaller firms oriented toward robot niches. Moreover, large diversified firms—especially those supplying a variety of types of programmable automation—may persist in the robot market even without earning profits there because (as with FMS) identification with the robot industry has strategic value.

Growth in applications will be a key to broadening the market. The rate at which robot use spreads to nonmetalworking industries will depend on many factors, including broad-based changes in manufacturing processes and standardization of equipment, languages, and interfaces (which may occur informally through the emergence of dominant products and vendors). Both growth in applications and reductions in cost should expand the market among small firms, in particular; at present, single-robot purchases are usually hard to justify on financial grounds.[72] Materials handling, assembly, and inspection applications, which can be found in virtually all manufacturing industries, will grow during this decade, in part because of advances in sensing and adaptive control (see ch. 3).

Robots are already considered feasible for materials handling in applications ranging from textile processing and apparel manufacture to personal-care product packaging, pharmaceuticals, and cigarette packaging. GCA, for example, is providing robots for materials handling in the printing and paper packaging industry. Assembly applications are becoming more common and diverse, especially in the electronics industry, with applications ranging from wire-harness assembly to insertion of components into circuit boards. Substantial markets for robots may also grow during the 1990's in nonmanufacturing applications, from battlefield missions to disposal of hazardous wastes to health-care services and food processing. Forestry, fishery, mining, agricultural, and oceanographic applications are also under development.

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[70] Stuart Brown, "Accurate Fixturing Not Required for Vision-equipped Robot System," *American Metal Market/Metalworking News*, Nov. 7, 1983.

[71] "Cincinnati Milacron Plans to Have Robots Made in Japan in 1984," *The Wall Street Journal*, Sept. 12, 1983.

[72] Steven M. Miller, "Potential Impacts of Robotics on Manufacturing Cost within Metalworking Industries," Doctoral Dissertation, Carnegie-Mellon University, 1983.

Table 61.—Prospects of Different Classes of Robot Vendors

Startups

Strengths:
- Few if any perceived or real dissatisfactions among end-users.
- Ability to attract and hire some of the most aggressive and smart individuals in robotics and related industries.
- Small size allows rapid shifts in strategies if necessary. (This was particularly important during the recession when certain kinds of orders became scarce.)
- Technological advances will probably come from smaller companies.
- Small starting base means that each order, regardless of size, is important. Thus, the best of these companies would tend to offer more support for a given size order.
- The best of these companies have attracted important venture capitalists, gaining impressive support and financial backing.

Weaknesses:
- Little name recognition for some of them.
- Far more competitive environment in robotics than is generally ideal for startups—i.e., little room for error or for learning from mistakes.
- Cannot afford to be consistently agressive in pricing.
- Need some early successes in order to retain venture capitalists. Otherwise cash flow insufficiency can become a fatal disease.

Large company entrants:

Strengths:
- Name recognition.
- Major financial strength.
- In many instances, applications of robots and other flexibile automation technologies in their own factories is a marketing plus.
- Already offer a large variety of products other than robots for different aspects of factory automation.

Weaknesses:
- Powerful financial strength for the corporation as a whole should not be interpreted as being equivalent to unlimited financial resources for the robot unit. The commitment of the company to robotics and how robotics fits into the company's overall strategy for factory automation will vary. (These commitments can diminish if the robot entity continues to underperform expectations.)
- The robot entity is one tiny group within the corporate organization. Robotics alone will make no difference to the profitability or growth of most of these companies.
- Large companies are often hampered by their own inertia.
- Inability to attract or keep aggressive entrepreneurial types for robot units. These individuals often prefer the looser organizational structure of smaller companies, where they can also get an equity position.

SOURCE: Laura Conigliaro, "Trends in the Robot Industry (Revisited): Where Are We Now?" *Proceedings of the 13th International Symposium on Industrial Robots,* April 1983.

Growth in systems applications and sales and advances in the automation of other production equipment will result in a rather small market for stand-alone robots, at least within metalworking industries. Moreover, these trends may also make it easier for firms to supply robots without manufacturing them themselves. Whether they do or do not produce manipulators, robot manufacturers are increasingly likely to produce their own computer controls. Also, the software side of the market should grow with software enhancements—for sensing, diagnostics, and other functions. The growth in systems applications and sales, the relative importance of controls, software, and customization, and the option of relying at least in part on foreign sources of low-cost hardware suggest that product differentiation and service may be more important than pricing for competition within the robot market.

Future trade patterns in robots would appear to depend on development of technology for new applications, prospects for continued cooperative efforts among producers, and the degree of emphasis placed on systems and services. Table 62 contrasts the distribution of robot applications in Japan and the United States.

The greater use of robots for assembly, "intelligent robots," and unsophisticated units aimed at small firms in Japan may benefit Japanese imports later in the decade.* However, simple comparisons of numbers made and used may be misleading. Most assembly and intelligent robots are relatively unsophisticated at this time. Moreover, the Japanese apparently consider U.S. assembly technology to be superior to their own. The Japan Economic Journal notes that the IBM 7565 system robots introduced in early 1983 "seem to be better than any factory assembly robots so far commercially developed in Japan" because of superior software, programing, sensors, and computerization.[73] Meanwhile, U.S. companies

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*Japanese firms have recently expanded their efforts to reach small manufacturers (and restaurants and schools) by offering robots through department stores. *Philadelphia Inquirer*, July 9, 1983.

[73] "Robot Makers are Sensing Strong U.S. Competition," *Japan Economic Journal*, Feb. 8, 1983.

Table 62.—Installed Operating Industrial Robots by Application, Dec. 31, 1982 (U.S. Definition)

	Japan		United States	
	Units	Breakdown in percent	Units	Breakdown in percent
Welding[a]	8,052	25.2	2,453	38.9
Painting	1,071	3.4	490	7.8
Assembly	6,099	19.1	73	1.2
Casting	557	1.7	875	13.9
Materials handling	6,797	8.1	1,300	20.6
Machine loading/unloading	2,578	8.1	1,060	16.8
Others	6,746	21.2	50	0.8
Total	31,900	100	6,301	100

[a] Japan Industrial Robot Association reported separately arc welding (3,874) and spot welding (4,278). Robot Institute of America (U.S.) did not distinguish between these two categories.

NOTE: These estimates are generally consistent with those of Table 59; the contrast illustrates the unreliable data problem.

SOURCE: Paul Aron, "The Robot Scene in Japan: An Update," Daiwa Securities America Inc., Sept. 7, 1983.

have begun to sell more robots in Japan. For example, a young firm called American Robot Corp. has sold electronic assembly robots in Japan, and it will produce robots there through a Japanese subsidiary to increase Japanese sales (it hopes to lower costs and prices).

Access to foreign markets may become more difficult and import competition may grow as a result of foreign policies supporting robots (and other forms of programmable automation) as a favored domestic product (see ch. 9). Spurring the production and use of robots, robot associations of various sorts exist in many countries, including Australia, Belgium, the United Kingdom, Denmark, France, West Germany, Italy, Japan, the United States, Singapore, Spain, Sweden, and China. These groups often work with policymakers on issues relevant to robot technology development, sales, and trade. A Swedish committee, for example, has proposed a campaign to increase robot production and use in Sweden, and Swedish-owned ASEA anticipates that robots will supersede autos as the main national product.[74]

France has even imported Japanese assistance to develop its robot business. In response to French Government requests for "Japanese cooperation in developing and introducing robots and other high-technology products as a step to revitalize the French economy," Yaskawa Electric Manufacturing Co. (Japan) and Cie Electro-mecanique (France) have teamed up. Yaskawa will supply large robots for CEM to market in France; it will sell small CEM robots in Japan; and it will help CEM produce large robots in France.[75] Also, ASEA will produce robots in France.

If robot systems grow in popularity, licensing may be the most effective way for Japanese manufacturers to reach the U.S. market, because most of them are primarily manipulator builders; U.S. strengths, by contrast, are in software and systems development. However, Japanese producers are working on robot systems of their own. For example, Sumitomo Shoji (a trading company), NEC (an electronics firm), and Dainichi Kiko (a robot maker) are developing robot systems with vision and voice sensors for sale in 1984.[76]

In the long term, U.S. manufacturers may become less interested in licensing as they gain experience in robotics, while the Japanese and others may establish U.S. subsidiaries to better provide service and hardware packages and to adapt to potential or actual restrictions on imports. Hitachi, for example, has a U.S. subsidiary which recently formed several independent sales and service centers to allow Hitachi to sell complete robot systems in the United States and to facilitate future robot production in the United States in the event robot imports are restricted. Hitachi now imports the basic robot and sells it with other equipment (e.g., welding and painting devices) and services provided by U.S. firms.[77]

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[74] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing" report of the April 1983, Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

[75] "Japan Agrees With France on Interchange of Robots," *Japan Economic Journal*, Jan. 11, 1983.

[76] Roy Garner, "Japanese Robot Industry Slows Down," *Financial Times*, Mar. 2, 1983.

An emphasis on service or on integrating robots into complex systems would argue against a strong import presence (in the traditional sense), because close relations with customers and retaining a local presence are important aspects of service provision and applications planning. Emhart Corp., for example, chose to work with ASEA of America in developing its first robot application because of the geographic proximity of the vendor's facilities to its own. Also, U.S. experts believe that U.S. firms lead in systems technology. However, a movement toward turnkey supply of systems is consistent with importation of hardware and components, packaged by domestic firms. Japanese hardware, in particular, is likely to grow more attractive as competition in Japan lowers prices.[78] Alternatively, foreign (and U.S.) firms may locate production or assembly facilities in different markets. ASEA, for example, has robot plants in Japan, West Germany, Spain, Sweden, and the United States.

Other PA Markets

Automated Materials Handling/ Storage/Retrieval Systems

Automated materials handling (AMH), storage and retrieval systems (AS/RS) and their components are supplied primarily by a few firms, which are typically suppliers of more conventional materials handling equipment and systems, such as conveyors and conveying equipment (SIC 3535), hoists, overhead cranes, and monorails (SIC 3536), and industrial trucks (SIC 3537). Principal vendors include Eaton-Kenway, Esco/Hyster, Litton, Clark Equipment, Jervis B. Webb, and SI Handling Systems. AMH firms have historically served customers in the mining and wholesale/retail trade industries as well as manufacturers, although products such as automatic guided vehicles ("robot carts") have recently been developed with particular attention to manufacturing-industry applications. AGV systems are already produced and used in Sweden, France, Italy, and West Germany, and British companies are also planning to enter the AGV market. The AS/RS market is more or less distinct from other AMH markets because the systems are more complex. They are generally sold in packages of hardware, software, engineering, and controls by firms operating in turnkey fashion.

The overall materials handling industry has contracted recently, in large part because of declining capital investment. Although imports in the conveyor, hoist, and industrial truck industries grew (in current dollars) by 14 to 20 percent in 1982, the ratio of imports to new supply (imports plus domestic production) for each of these industries overall was less than 10 percent.[79] However, there is a growing tendency for foreign sourcing of hardware in these markets, as in others. And, for some AMH products, import competition is strong. Makers of other PA equipment are entering the market, and some materials handling companies are expanding their involvement in order to have a stake in the manufacturing automation market as a whole. Harnischfeger Corp., for example, seeks to increase its materials handling business and shift away from its predominant business in heavy equipment. It is hiring more engineers, increasing AMH R&D and applications engineering, and developing new controls for AMH systems.[80]

While spending for materials handling equipment is strongly tied to business investment patterns in general, new interest among manufacturing firms in automating and linking materials handling and production equipment will create new demand. Indeed, a major trade association, the Material Handling Institute, replaced their 1984 "Automated Material Handling and Storage System Conference" with an "Integrated Systems Conference" and formed an advisory "Advance Technology Council."[81] However, since FMS and other aspects of production integration are still being developed and are of limited use, highly integrated systems are not likely to have a major influence on the materials handling market during this decade. Also, AS/RS have tended to be practical only for very large-volume storage needs and relatively frequent turnover of inventories, although smaller systems are being developed.

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[77] Lauri Giesen, "Hitachi Offering Complete Robots in U.S," *American Metal Market/Metalworking News*, Apr. 25, 1983.

[78] "Matsushita Electric is Japan's Top Robot Maker," *Japan Economic Journal*, May 24, 1983.

[79] U.S. Department of Commerce, *1983 Industrial Outlook*. Note that these figures may not capture larger penetrations for specific products.

[80] Lauri Giesen, "Harnischfeger Veers to Material Handling," *American Metal Market/Metalworking News*, Jan. 16, 1984.

Manufacturing Resources Planning (MRP) and Other Management Systems

The market for MRP and other management systems is a part of the overall market for management software. These systems have been sold to a wide range of firms, including metalworking, electronics, and miscellaneous manufacturing companies, firms which in many cases are unlikely to buy other, production types of programmable automation. They are sold by computer vendors, software houses, engineering and other consulting firms, and service bureaus. Professional societies (e.g., the American Production and Inventory Control Society) are important in promoting the diffusion of such systems.

MRP systems are available primarily as software packages for mainframes and minicomputers. Sperry Corp., for example, offers a manufacturing control system with "modules" for bill of materials generation and inventory control, manufacturing and purchase-order control, materials requirements planning for scheduling, and production-costing and "shop-floor control" functions.[82] Several other companies also offer such multifaceted systems. Availability of minicomputer versions, and more recently microcomputer-based systems, has opened the market to more buyers and sellers. Also, in many cases users develop their own systems. Management software ranges in price from under $1,000 for single-function, microcomputer packages to over $250,000 for complex multifunction "MRP II" packages.[83]

Many vendors and consultants are hoping to increase their sales to smaller firms. The availability of micro-based systems in particular is expected to enlarge the small-firm market. Digital Microsystems, Inc., for example, offers an MRP system aimed at companies with up to $25 million in sales. The system, offered with training, includes a local-area network, MRP software, and software for office automation and business graphics. As this example illustrates, vendors may try to meet customer needs with packages that simultaneously computerize a number of functions. While the erratic production flow of small, batch-production firms makes planning for MRP challenging, the potential for increased inventory control afforded by such systems may reduce the financial volatility typical of such firms.

Computer-Integrated Manufacturing: Potential Market Developments

A separate "CIM market" does not exist. Although users of programmable automation are achieving greater integration of their equipment, systems, and activities; and some vendors, in turn, are touting their ability to implement CIM and meet diverse needs for manufacturing integration, no one yet sells "CIM" as a total product nor has any vendor fully implemented CIM. Indeed, some in industry contend that users are still pioneering the application of CIM. If needs remain highly idiosyncratic (which is quite likely) and attempts at CIM few in number (which is possible), most CIM may be developed by users; in that case, a true market will not exist. Development by users is especially likely for large firms; smaller firms may lack the resources to develop their own systems (or to integrate production completely).

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[81] "Newsletter," *Modern Materials Handling*, April 9, 1984.

[82] "Sperry Unveils Manufacturing Control System," *Computerworld*, Dec. 12, 1983.

[83] "Micro Software Brings Material Control to the Desk Top," *Modern Materials Handling*, Jan. 23, 1984.

The fragmentation of PA supply among myriad firms of different types and sizes may impede development of a CIM market, especially in the absence of standard equipment and interfaces. A spokesman for Caterpillar Tractor, for example, has argued that a major barrier to buying or using CIM is the absence of standard programing languages, data formats, communications protocols, teaching methods, controls, and well-developed offline programing capabilities.[84] This view is echoed by others in industry.

Insofar as commercial supply does develop, CIM may be provided through modular or all-at-once packages. Modular systems, which can be expanded over time, could be provided by various types of firms, from those specializing in one type of automation to those offering a full range of systems. The success of the commercial CIM packages expected to be offered in the mid-1980's by Hitachi and by a Norwegian-West German joint venture may provide a measure of the potential for a true CIM market.

A key uncertainty for a possible CIM market is the role of large, "supermarket" suppliers of programmable automation. The advantage that may accrue to suppliers of multiple forms of PA is hard to measure. In principle, such an advantage may exist because of what economists call "economies of scope"—savings in costs in the production of related products through joint R&D, marketing, component manufacturing, and accumulation of know-how. The potential automation "supermarkets"—GE, IBM, Westinghouse, et al.—have each expanded their automation production capabilities within the past few years. GE, for example—already an established manufacturer of industrial electronics (including programmable controllers and local communications networks)—acquired Calma for computer graphics and Intersil for integrated circuits; formed a joint venture with Structural Dynamics Research Corp. to design and sell CAE programing; developed and licensed robots for assembly, painting, welding, and other applications; and developed optoelectronics for machine vision. GE has also established a manufacturing automation systems engineering unit, and expanded its research capability in electronics, including VLSI technology. By contrast, Westinghouse acquired Unimation but divested other production operations (for CNC, parts programing, and time-sharing) in a shift toward service business and away from manufacturing.[85]

Size may not be essential for broad PA capability. GCA, for example, is a relatively small producer of robots (and other equipment) that has established links with Japanese and U.S. firms to supply robotics hardware, vision systems, and CAD units; its own efforts are concentrated on controls technology and software development.

Regardless of size, know-how will be particularly important for a CIM market: In the words of a GE representative, "The factory of the future is a knowledge game, not a hardware game."[86] Consequently, it is likely that systems houses and engineering consulting firms will play a major role in providing CIM. Such firms have already played an important role in developing markets for individual types of programmable automation. They are a conduit for applications engineering and other services for tailoring available equipment to specific needs. Also, they are sometimes better able to obtain customer confidence than are vendors who have a stake in a given product line. Because hardware production is not essential for CIM "supply," some analysts believe that nonmanufacturing organizations such as Battelle Memorial Institute, Booz-Allen & Hamilton, and A. T. Kearney may become important in the CIM market.[87]

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[84] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

[85] Bruce Vernyi, "Westinghouse Poised to Sell CNC, Parts Programming, Time-Share Lines," *American Metal Market/Metalworking News*, Aug. 8, 1983.

[86] Jack Norman, "Impact of Automation Downplayed," *Milwaukee Journal*, June 14, 1983.

Since PA is commonly construed by vendors and users alike to be an answer to manufacturing problems, companies who sell many types of automation and can integrate them may be assumed to have a better notion of what constitutes the right solution to a given production problem, especially if they use PA themselves. Because the firms that seek to be PA supermarkets have each accumulated substantial experience with programmable automation in their own production operations, the know-how (and reputation) with which they enter the market might be a critical advantage. On the other hand, a combination of consultants or service bureaus and smaller, specialized producers of PA might achieve the same end. The viability of the latter approach depends in part on whether and when standard components and/or interfaces become available.

Computer vendors will likely play a major role in CIM supply, given the common element of computerization in PA products, and because of these vendors' own experiences in adopting advanced automated systems. Computer vendors (and even semiconductor manufacturers) have demonstrated a growing interest in participating in PA supply generally. IBM, for example, recently reorganized its Industrial Automation, Graphics Systems Programs, and Industry Applications system units into a single unit to focus the management of its industrial automation business.[88] Moreover, the growth of computerization without integration—through so-called islands of automation and through growth in computerized management systems (particularly those aimed at nonproduction activities)—may benefit computer vendors by providing both a basis for future integration and a market for interfaces and networking systems. Finally, the overall spread of computerization in office as well as production activities may convey an advantage to computer vendors, who are becoming increasingly familiar to managers of potential customer firms.*

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[87] "G.E. is Seeking to Dominate Robot Field," Minneapolis, *Finance & Commerce Daily*, Oct. 13, 1983.

[88] Mitchell York, "IBM Forms Units for Distribution, Industrial Systems," *Computer Systems News*, Nov. 21, 1983.

*Also, AT&T may become involved in this market. It has planned to join with Bailey Controls (division of Babcock & Wilcox) "in linking communications technology with process control systems, numerically controlled machines, mainframe computers, engineering automation systems and personal computers." "AT&T Unit, Bailey Set Linkup in Technology," *American Metal Market/Metalworking News*, Nov. 21, 1983.

Themes and Conclusions

OTA's evaluation of programmable automation industries reveals several broad themes. These are: 1) there has been a discrepancy between vendor and buyer views of needs and capabilities; 2) systems planning and other services are key features of PA supply, while manufacturing itself plays a smaller role; 3) vendors are likely to package and/or distribute hardware and software elements made by several firms; 4) both large and small firms have played distinctive roles in the development of PA markets; and 5) governments have had a major influence on PA market development.

Vendors v. Users.—Despite past and predicted rapid growth rates, key barriers to further market growth have been: 1) the need for users to learn how to adopt programmable automation successfully; 2) vendor inability to fully meet user needs and wants; and 3) the immaturity of automation technology, principally for system integration. Programmable automation seems to require greater customer sophistication than conventional automation if applications are to succeed. Vendors continue to speak of the need for "missionary work," for educating the prospective and actual buyer. The discrepancy between vendor offerings and user needs lies behind the slow start of automation industries; it is typical of new technology markets. What is unusual about these markets, however, is the growing role of user-producers: companies are developing proprietary equipment and systems and increasingly seeking to market them (or associated know-how) externally.

Systems and Service.—Automated equipment can be sold on a stand-alone basis, but is increasingly sold in systems that are tailored to individual needs through control technology and software modifications. Demands that users plan and adjust their organizations to accord with new processes grow with the size and complexity of the installation. Consequently, vendors undertake sophisticated marketing efforts and provide a variety of services to train users to plan for, operate, and maintain their systems. Thus, PA vendors offer both services—the development of applications, systems, and support functions—and goods; vendors are not all manufacturing firms, per se. This trend resembles conditions in the computer industry generally. Indeed, there are some firms and divisions of firms that are strictly service-oriented; they provide PA consulting and engineering services. Overall, the proportion of manufacturing activity in this industry is declining as the role of services grows; the absolute level of manufacturing activity may also decline due to outsourcing practices.

Cross-fertilization.—Licensing, outsourcing, mergers and acquisitions, limited-equity investments, and joint ventures have been frequent means of entry into PA markets. These arrangements enable firms with different strengths to enter markets for complex products quickly. They also provide a means for distant firms to enter remote markets. The cross-fertilization trend for programmable automation is symptomatic of trends affecting the overall information-processing and electronics industries. These broad industrial categories have seen a decline in levels of vertical integration because new products are becoming more complex, product change is accelerating, international competition is strengthening, and product development costs are rising.

Many cooperative ventures link firms from different countries. In particular, substantial numbers of U.S. firms license or buy Japanese hardware and European software; Japanese firms have licensed U.S. software recently, as they earlier did hardware. Collaboration facilitates entry into foreign markets, especially in the case of Japan; local firms provide remote ones with distribution and support networks. Cooperative ventures have thus hastened the international diffusion of PA technology and the growth of global markets.

The long-term implications of cross-fertilization are unclear. They depend on whether firms can and do acquire the strengths of their partners and therefore become new, independent competitors. Because of this possibility, some pessimists characterize cooperative ventures as "Trojan Horses" that may harm domestic firms in the long run.

Firm Size.—Because large and small firms offer both advantages and disadvantages in the PA market, it is hard to predict future tendencies for industrial structure. Typically, industries grow as small, innovative firms expand or are acquired; remaining small firms serve specialized niches. This pattern can be seen with programmable automation, but a larger role for small firms is also possible. This is in part because vertical integration is relatively uncommon. Small firms may continue to find opportunities as service bureaus or consultants. Also, the proliferation of software packages and limited-function, low-cost equipment and systems may continue to provide a role for small firms in PA supply.

The emergence of standards for components and/or interfaces may also help smaller vendors, even if standards develop de facto as the product designs of larger, dominant manufacturers. This has been the pattern in the computer industry. By contrast, large firms may offer more experience with applications and may be relatively well-suited to assembling large, complex systems.

Government Role.—Governments have played key roles in the development of U.S. and foreign markets for PA. As described in chapter 9, differences in government roles reflect differences in national context (labor market conditions, industrial composition, technology strengths, etc.). The U.S. Government role has been largely limited to support for military programs aimed at meeting defense procurement needs. Other governments appear to have provided more support for commercial PA development and use, although the effectiveness of such support is hard to appraise.

Chapter 8

Research and Development

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Chapter 8

Research and Development

Summary

A wide variety of research and development (R&D) efforts, ranging from very basic, long-term research to market-oriented, short-term product development, are applicable to programmable automation (PA). The principal fields which contribute to such R&D are computer science; electrical, mechanical, industrial, and manufacturing engineering; and metallurgy.

Both government and industry are major funders of R&D in automation technologies. The Federal Government budgeted approximately $80 million of work in this area in fiscal year 1984. This work is undertaken in industry, university, and government laboratories.

The bulk of Federal funding for automation R&D (roughly $64 million) comes from the Department of Defense (DOD), primarily through its Manufacturing Technology (ManTech) Program. This work is aimed at facilitating technologies that would improve defense production. Other agencies in DOD fund work with potential applications for both defense manufacturing and the battlefield. While DOD's funding of automation technology R&D has had some benefits for civilian manufacturing, its programs are not aimed at technological developments that would have wide applications outside of defense needs. In addition, the technologies developed through DOD tend to be some of the most complex, useful largely in the advanced aerospace and electronics industries.

Civilian agency programs in automation R&D are relatively small. The National Aeronautics and Space Administration (NASA) funds work primarily in robotics-related tools for use in space, much of which, like DOD's programs, is at the very sophisticated end of the technology spectrum and has limited commercial spinoffs. The National Science Foundation (NSF) funds a wide range of more basic work related to programmable automation, as well as helping to establish centers for university-industry cooperation. The National Bureau of Standards' (NBS) laboratory is the Government's primary in-house performer of R&D for manufacturing. Their work includes a large-scale test arena for computer-integrated manufacturing (CIM) techniques and interface standards, known as the Automated Manufacturing Research Facility (AMRF).

Industry funding for R&D in this area, though hard to gauge precisely, seems to be healthy and escalating rapidly, especially as the market for programmable automation devices becomes more competitive. The perception among technology researchers seems to be that industry is "where the action is" for automation R&D. Industry spending in the machine tool, CAD, and robotics industries alone amounted to approximately $250 million to $400 million in 1983. There is also evidence of a proliferation of industry-university cooperative research.

Foreign industries and cooperative industry-government laboratories are also pursuing very active PA research programs. Japan, West Germany, and Sweden—and to a lesser extent the United Kingdom and France—have significant research efforts in this area. The traditional U.S. lead in development of these technologies has been eroded, although the United States is still a strong leader in many technical areas. However, Japan has been more active than either the United States or Western Europe in application of the technologies.

Introduction

The aim of this chapter is to assess the context for R&D in programmable automation. The chapter begins with general background on R&D and its funding, and examines in detail Federal funding of R&D in programmable automation. Industry R&D efforts are outlined, and a final section brings forth some of the highlights in international comparisons in R&D.*

"R&D" is often used as a catch-all term for a wide variety of activities which range from the most esoteric science (far at the "R" end of the range) to the most down-to-earth product development efforts (pure "D"). And because programmable automation draws on such a wide variety of science and engineering fields—computer science; manufacturing, electrical, mechanical, and industrial engineering; and metallurgy, to name just the primary ones—it can be difficult to isolate those efforts which should be considered relevant.

NSF offers the following definitions:

- In **basic research** the objective of the sponsor is to gain fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without having specific applications toward processes or products in mind.
- In **applied research** the objective of the sponsor is to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.
- **Development** is systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes. It excludes quality control, routine product testing, and production.[1]

Classification of individual R&D efforts into such categories is often not completely straightforward, and involves a great deal of judgment. Moreover, this distinction has become increasingly less clear-cut in recent decades. Science and technology have become harder to differentiate, and universities have more actively sought industrial funding. R&D efforts at all three levels—those considered basic research, applied research, and development—are important for programmable automation.

As figure 33 indicates, the Federal Government and industry are the two dominant contributors to R&D spending in the United States. Universities, State and local governments, and other nonprofit institutions make a small addition of their own funds. In 1983, out of a total R&D pool of $86.5 billion, the Federal Government spent almost $40 billion, or 46 percent. Industry contributed $44.3 billion, or 51 percent. NSF estimates that total R&D funding will be $97 billion for 1984. Industry overtook the Government in spending for R&D in 1980, according to NSF data (see fig 34). While the Federal Government's spending for R&D has remained relatively constant in 1972 dollars, industry's share grew substantially in real dollars in the 1970's and early 1980's.

Industry is also the dominant performer of R&D, receiving 74 percent of the total of $86.5 billion in 1983. Universities received 9 percent of those funds, and Federal agencies or R&D centers 14 percent.

Within the Federal Government, tables 63 and 64 show that defense-related R&D is the single largest and fastest growing component

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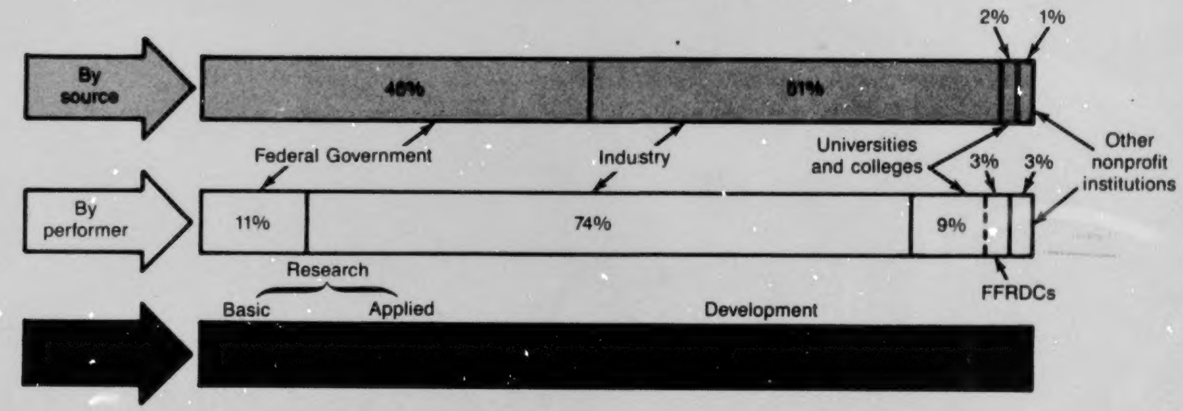
*Chapter 9 covers foreign R&D mechanisms and institutions. The content of foreign R&D in automation will be outlined at the end of this chapter.

[1] National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1981, 1982, and 1983* (Washington, D.C.: National Science Foundation, 1982), p. 1.

Figure 33.—The National R&D Effort

Expenditures for R&D = $97 billion, 1984 (est.)



SOURCE: National Science Foundation, preliminary figures from *National Patterns of Science and Technology Resources, 1983*, in press.

of Federal R&D funding. Nondefense R&D spending by the Federal Government has declined in real terms under the Reagan administration, primarily due to dramatic reduction in nondefense applied research, development, and demonstration activities. Basic research has been relatively healthy, albeit with a few shifts in priorities. Defense-related R&D is estimated at $30.2 billion in 1984, accounting for 66 percent of Federal spending for R&D.[2]

The United States has historically spent far more than its allies on R&D. However, figure 35 shows that foreign expenditures for R&D have grown faster than those in the United States. In addition, both Japan and West Germany have exceeded the United States in nondefense R&D as a percentage of gross national product (GNP)[3] (see fig. 36).

Funding and Performers of R&D in Programmable Automation

Overview

For purposes of this study, R&D in programmable automation is work which is centrally concerned with one or more of the technologies identified in table 5 in chapter 3. Industry and the Federal Government are the primary sources of funding for such work in the United States, although universities and State governments have made small contributions.

Figure 37 is a rough map of the performers of R&D related to programmable automation. The Federal Government's interest in such work comes from several agencies, each with

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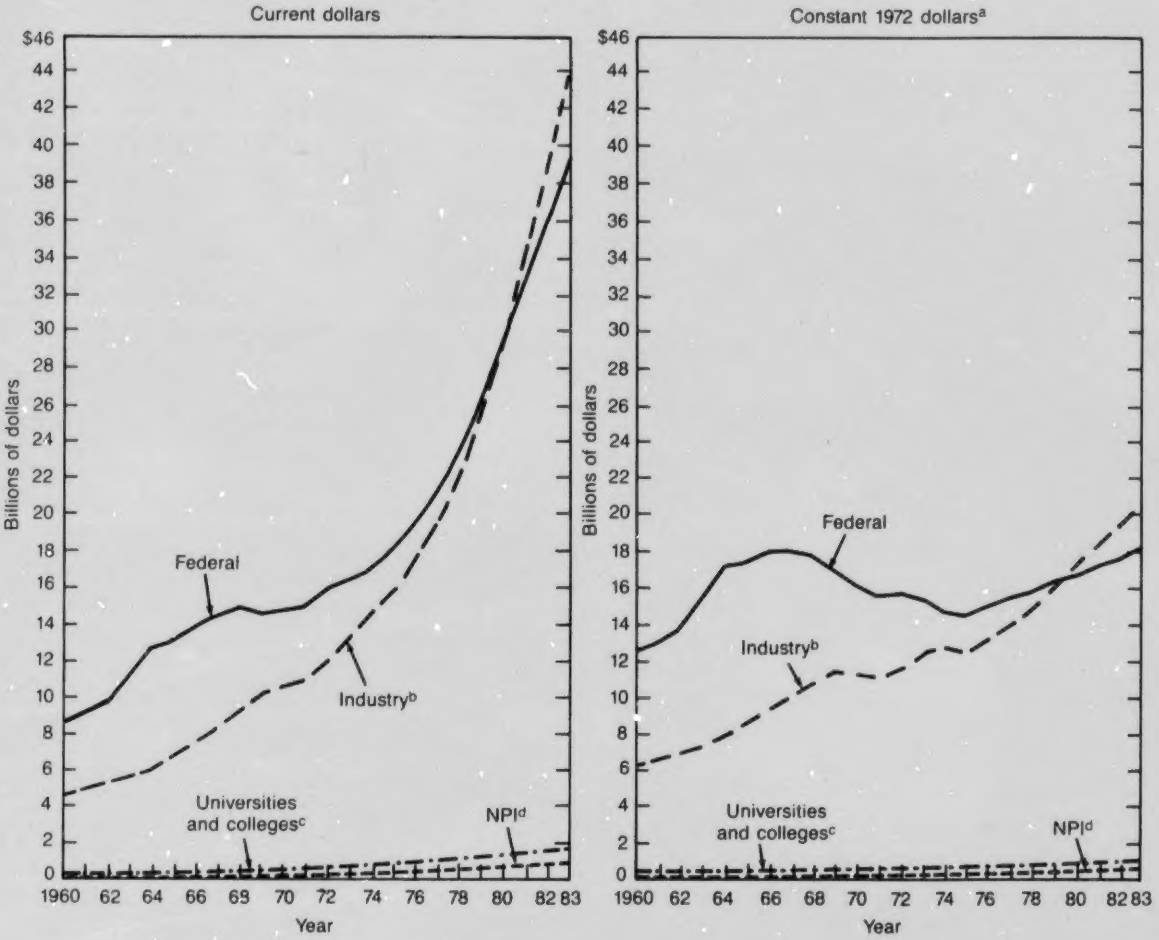
[2] W. C. Boesman, "U.S. Civilian and Defense Research and Development Funding: Some Trends and Comparisons With Selected Industrialized Nations," Congressional Research Service, Report No. 83-183, Aug. 29, 1983; and American Association for the Advancement of Science, *AAAS Report IX: Research & Development, FY 1985* (Washington, D.C.: AAAS, 1984).

[3] Ibid.

Figure 34.—National Expenditures for R&D by Source



Current dollars

Constant 1972 dollars[a]

[a] GNP implicit price deflators used to convert current dollars to constant 1972 dollars.

[b] Data are not available on industry resources for research in the psychological and social sciences.

[c] Includes State and local government sources.

[d] Other nonprofit institutions.

SOURCE: National Science Foundation, *Science Indicators—1982* (Washington, D.C.: National Science Board, 1983).

Table 63.—Major Components of Federal Funding for R&D[a] (budget authority in billions)

	Fiscal year 1967 actual	Fiscal year 1972 actual	Fiscal year 1982 actual	Fiscal year 1983 actual	Fiscal year 1984 estimate	Fiscal year 1985 budget
Current dollars:						
Defense[b]	$8.8	$9.2	$22.9	$25.6	$30.2	$37.9
Non-Defense[c]	8.3	7.9	15.8	14.4	15.7	16.4
Space[d]	4.7	2.7	3.6	1.7	1.9	2.3
Health[e]	1.3	2.0	4.1	4.5	5.1	5.2
Energy[f]	0.6	0.6	3.5	2.9	2.8	2.7
General science[g]	0.5	0.7	1.5	1.6	1.9	2.2
All other	1.2	1.9	3.1	3.7	4.0	4.0
Total R&D	$17.1	$17.1	$38.7	$40.0	$45.9	$54.3
Constant fiscal year 1972 dollars:						
Defense[b]	$12.4	$9.2	$9.8	$10.4	$11.9	$14.2
Non-Defense[c]	$11.7	$7.9	$7.2	$6.4	$6.6	$6.6
Space[d]	6.6	2.7	1.7	0.8	0.8	0.9
Health[e]	1.8	2.0	1.9	2.0	2.2	2.1
Energy[f]	0.8	0.6	1.6	1.3	1.2	1.1
General science[g]	0.7	0.7	0.7	0.7	0.8	0.9
All other	1.7	1.9	1.4	1.6	1.7	1.6
Total R&D	$24.0	$17.1	$17.0	$16.8	$18.5	$20.8

[a] Includes conduct of R&D and R&D facilities.
[b] Includes DOD and defense activities in DOE.
[c] Includes all R&D in defense.
[d] Reflects AAAS' estimates for NASA less space applications and aeronautical research.
[e] For fiscal years 1982-1985, includes health research in HHS, VA, Education, and EPA. Fiscal year 1967 and 1972 based on OMB data for health research in all Federal agencies.
[f] Includes NRC, EPA energy research, and DOE less defense activities and general science.
[g] Includes NSF and DOE general science.

SOURCE: American Association for the Advancement of Science, *AAAS Report IX: Research & Development, FY 1985* (Washington, D.C.: AAAS, 1984). AAAS estimates based on data from OMB and agency budget justifications. Conversion to constant FY 1972 dollars by AAAS based on OMB deflators.

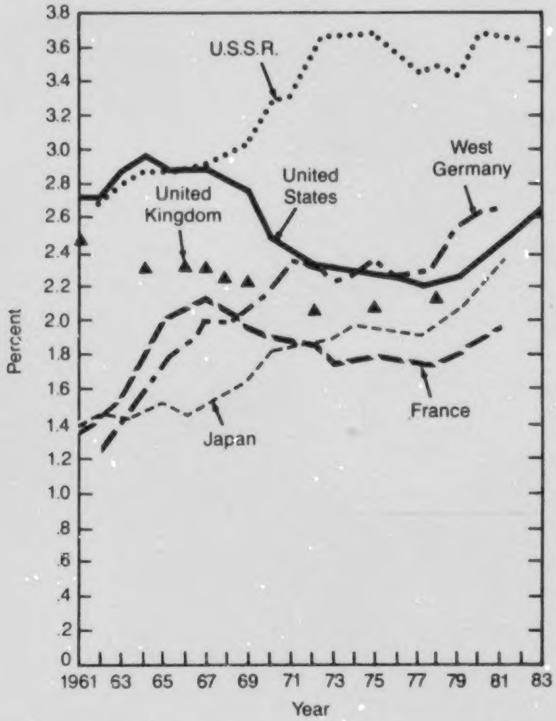
Table 64.—R&D in Selected Agencies[a] (budget authority in millions)

	Fiscal year 1983 actual	Fiscal year 1984 estimated	Fiscal year 1985 budget (proposed)	Percent change: Fiscal year 1984-85 Current dollars	Percent change: Fiscal year 1984-85 constant dollars
DOD	$23,673	$27,876	$35,336	+26.8%	+20.9%
DOE-defense	1,975	2,286	2,522	+10.3%	+5.3%
(Total defense)	(25,648)	(30,162)	(37,858)	(+25.5%)	(+19.8%)
DOE-general science	568	639	745	+16.5%	+11.3%
DOE-energy	2,622	2,610	2.499	−4.3%	−8.5%
NASA	2,735	2,971	3,466	+16.7%	+11.4%
NSF	1,059	1,247	1,427	+14.4%	+9.2%
NIH	3,814	4,264	4,356	+2.2%	−2.4%
Other HHS	557	613	597	−2.7%	−7.0%
USDA	885	923	926	+0.4%	−4.1%
EPA	234	248	280	+12.7%	+7.6%
Education	102	111	107	−3.3%	−7.5%
NOAA	213	240	167	−30.4%	−33.5%
NBS	94	95	103	+8.2%	+3.5%
USGS	149	162	148	−8.6%	−12.7%
Bureau of Mines	97	87	69	−21.0%	−24.5%
All other	1,265	1,533	1,555	+1.5%	−3.0%
(Total nondefense)	(14,393)	(15,743)	(16,444)	(+4.4%)	(−0.3%)
Total	$40,042	$45,905	$54,301	+18.3%	+12.7%

[a] Includes conduct of R&D and R&D facilities.

SOURCE: American Association for the Advancement of Science, *AAAS Report IX: Research & Development, FY 1985* (Washington, D.C.: AAAS, 1984), using "OMB Data for Special Analysis K," as revised, and agency budget justifications.

Figure 35.—National Expenditures for Performance of R&D[a] as a Percent of Gross National Product by Country

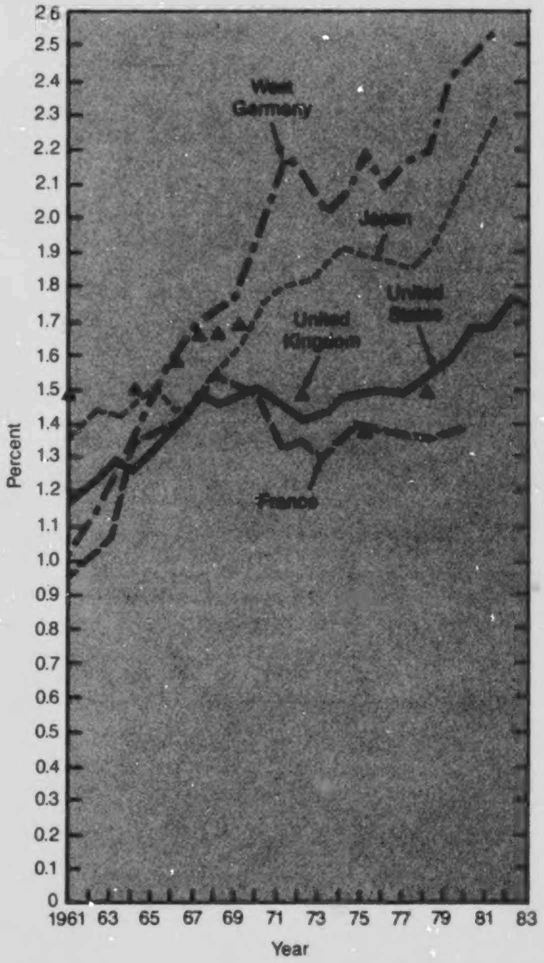


[a] Gross expenditures for performance of R&D including associated capital expenditures, except for the United States where total capital expenditure data are not available. Estimates for the period 1972-80 show that their inclusion would have an impact of less than one-tenth of 1 percent for each year.

NOTE: The latest data may be preliminary or estimated.

SOURCE: National Science Foundation, *Science Indicators—1982* (Washington, D.C.: National Science Board, 1983).

Figure 36.—Estimated Ratio of Civilian R&D Expenditures to Gross National Product for Selected Countries

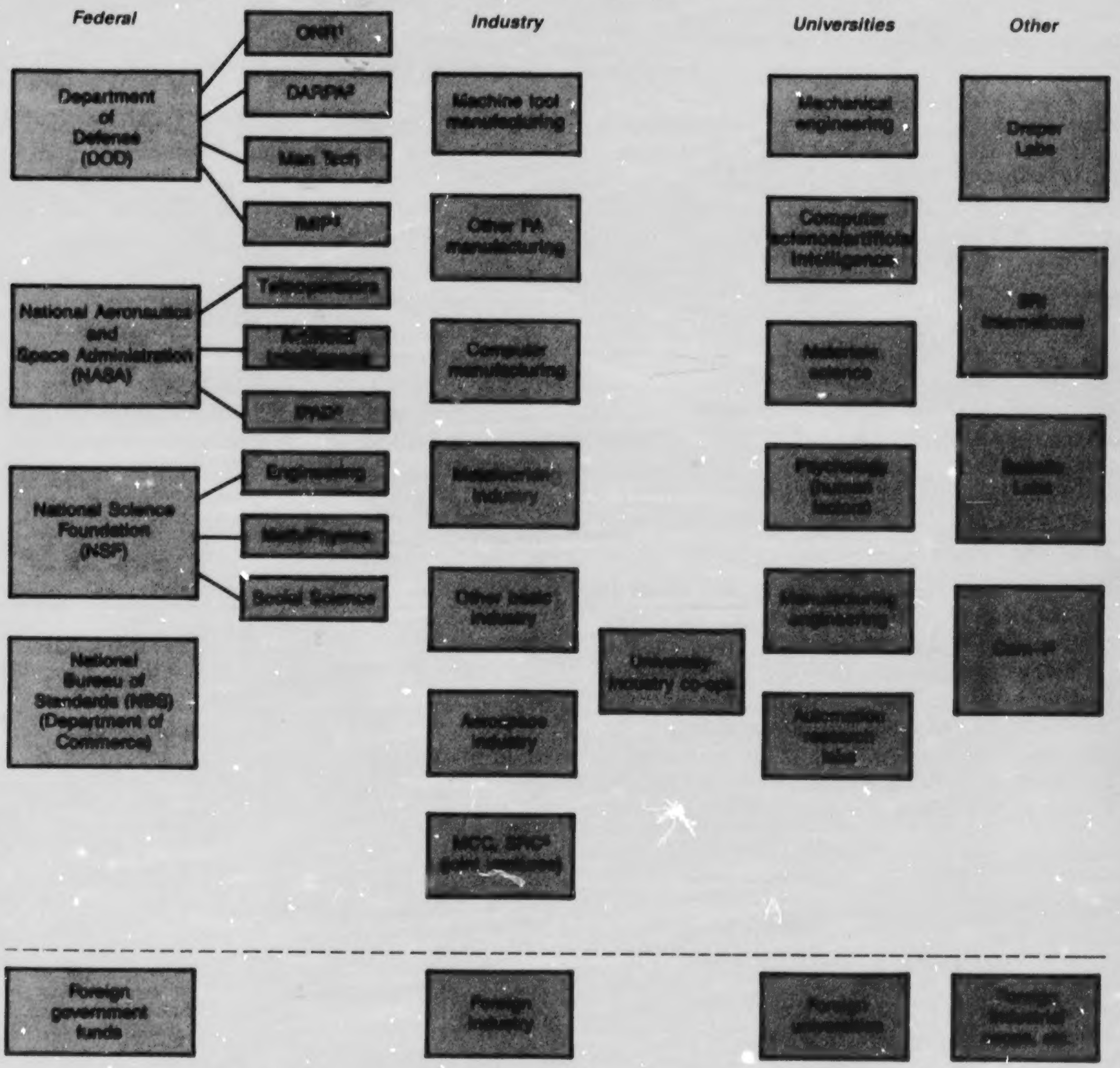


[a] National expenditures excluding Government funds for defense and space R&D.

SOURCE: National Science Foundation, *Science Indicators—1982* (Washington, D.C.: National Science Board, 1983).

different approaches and goals. DOD funds very substantial amounts of R&D in automation technology—primarily in industry labs—both to save the Government money on its purchases of manufactured goods, and to develop technologies which may have applications for manufacturing or in battlefield situations. NBS, under the auspices of the Department of Commerce, pursues automation research because of the standards and measurement issues involved, and as a result of a longstanding mandate to investigate various aspects of computer technology. NASA looks to automation technologies to help plan and conduct space missions. NSF funds a broad range of automation research, primarily at universities, as part of its general mandate to support work in science and engineering and encourage technology transfer to industry. And finally, an assortment of other agencies are exploring robotics, primarily for nonmanufacturing applications such as maintenance in nuclear powerplants.

Figure 37.—The Range of Programmable Automation Research and Development


Federal
Industry
Universities
Other
Department of Defense (DOD)
ONR1
DARPA2
Man Tech
IMIP3
National Aeronautics and Space Administration (NASA)
Teleoperators
Artificial intelligence
IPAD4
National Science Foundation (NSF)
Engineering
Math/Physics
Social Science
National Bureau of Standards (NBS) (Department of Commerce)
Machine tool manufacturing
Other PA manufacturing
Computer manufacturing
Metalworking industry
Other basic industry
Aerospace industry
MCC, SRC5 (joint ventures)
University-industry co-ops
Mechanical engineering
Computer science/artificial intelligence
Materials science
Psychology (human factors)
Manufacturing engineering
Automation research labs
Draper Labs
SRI International
Battelle Labs
CAM-I6
Foreign government funds
Foreign industry
Foreign universities

Key: 1. ONR = Office of Naval Research.
2. DARPA = Defense Advanced Research Projects Agency.
3. IMIP = Industrial Modernization Incentive Program.
4. IPAD = Integrated Program for Aerospace Vehicle Design.
5. MCC = Microelectronics & Computer Corp.
SRC = Semiconductor Research Corp.
6. CAM-I = Computer-Aided Manufacturing—International.

SOURCE: Office of Technology Assessment.

As the second column of figure 37 displays, the major players in R&D in industry are those who make automation technology and those who use it, categories which have merged to some extent (see ch. 7). In addition, cooperative interindustry research efforts play a small, though perhaps increasing, role. As will be discussed below, industry spending on automation R&D is hard to gauge accurately because some privately held firms do not divulge the information; other, larger companies do not disaggregate the portion of their R&D budget spent for programmable automation.

Universities (column 3) pursue automation research through a handful of traditional departments, and in some cases through new automation research labs and/or cooperative efforts with industry. They are still the centers of basic research, although they are increasingly working on applied research and even development topics.

Finally, several other independent laboratories (column 4) have played key roles in automation R&D, and one association of various industry, government, and foreign interests—Computer Aided Manufacturing-International (CAM-I)—funds research projects at university and industry labs, and in some cases serves as a forum for technology transfer between companies or from universities to industry.

The remainder of this section describes in more detail the particular programs and levels of funding undertaken by the primary sponsors of programmable automation R&D—government and industry.

Federally Funded R&D Efforts

The Department of Defense

Manufacturing Technology.—The bulk of DOD's automation technology research is conducted under its Manufacturing Technology, (ManTech) Program, which is funded at $200 million in fiscal year 1984. The Army, Navy, and Air Force's allocations within ManTech have been somewhat unstable over the past few years,* although DOD plans a substantial increase in all ManTech funding within the next few years (see table 65). The goal of the program is to develop and apply productivity-enhancing manufacturing technologies, primarily to military contractors. ManTech also attempts to actively transfer manufacturing technologies to industries not necessarily involved in military work.**

Although the Pentagon has been involved in manufacturing technology for several decades, the current ManTech program essentially began in 1960. It has helped develop and apply several historically significant technologies, including numerically controlled machine tools and the APT language for those tools, as well as calculators using integrated circuits.

ManTech projects aim for a grey area between applied research, development, and application. Although the program purports not to "develop" technology, it nonetheless contributes to that process. The standards of the program require that the projects are technically feasible, generically applicable, and have a level of cost and risk such that private industry cannot or will not fund the work.

ManTech contracts with industry to (in its terms) "procure" a manufacturing process

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*In particular, the Army's ManTech program suffered a substantial cut in 1983 funds when the House Appropriations Subcommittee on Defense decided that Army ManTech did not belong in the procurement budget, but rather in R&D. The subcommittee cut the entire amount ($110 million) requested in the procurement category, but later restored $50 million in R&D funds. Pentagon officials argue that although ManTech does look like R&D in some respects, it is better for the program to be administered in procurement, where managers are more likely to be familiar with manufacturing. As of early 1984, the subcommittee had persuaded DOD to put the bulk of ManTech Funding in R&D. There is some worry that R&D funding may be more unstable, however. (Lloyd Lehn, ManTech Program Officer, The Pentagon, personal communications.)

**The General Accounting Office (GAO) has criticized the ManTech program for having inadequate documentation of the effectiveness of its technology transfer efforts ("Manufacturing Technology—A Cost Reduction Tool at the Department of Defense That Needs Sharpening," September 1979). As the Pentagon concedes, ManTech staff often do not know to what extent industries pick up technologies developed under the program. GAO plans to publish an update of that report in the spring of 1984.

Table 65.—Funding for the DOD Manufacturing Technology Program[a] (in millions)

	Fiscal year					
	1980	1981	1982	1983	1984	1985 (preliminary)
Army	68	76	95	41	86	81
Navy	14	12	29	32	57	68
Air Force	56	66	86	59	57	62
Total	138	154	210	132	200	211

[a] As of January 1984.

SOURCE: Department of Defense.

that enhances particular DOD manufacturing applications. For example, the Air Force ManTech staff might decide that soldering of particular printed circuit boards could be automated if someone would apply existing soldering and computer control technologies and build an interface between the computer and soldering machines. The Air Force would request competitive bids to do this work, and would then establish a contract and a schedule with a particular firm. (ManTech did, in fact, fund the automation of a wave soldering machine for printed circuit boards used in several weapons systems. The new process is claimed to save $1.1 million per year; ManTech's investment was $450,000.)[4]

Of $200 million in fiscal year 1984 funding for ManTech, $56 million is concerned with computer-aided manufacturing. Other technical areas funded by ManTech include electronics, inspection and test techniques, production of metal and nonmetal parts, and ammunition production. Pentagon directors of the program estimate that the vast majority of ManTech funds are spent for R&D in private industry—100 percent of Air Force ManTech funds, 75 percent of Navy funds, and 50 percent of the Army's. Roughly 400 to 500 projects are active at a time, covering an extraordinary range of subjects from rocket nozzle improvements to ambitious efforts to integrate programmable automation devices.

The latter are the most relevant to this study. The Air Force began its Integrated Computer-Aided Manufacturing (ICAM) program in 1978. It is the largest single expenditure in ManTech, funded at $18 million in 1983. It is also one of the most prominent and broad-based efforts in programmable automation systems R&D. ICAM has developed "architectures" for the structure and control of automated manufacturing, and it has funded a variety of work on the foundations of CIM. ICAM is being phased out as a separately budgeted line item in the Air Force ManTech program, though the program's directors intend to continue work in integrated manufacturing.

The Army's ManTech program has a similar project clearly related to programmable automation: Electronics Computer-Aided Manufacturing (ECAM). It is similar in concept to ICAM although newer and much less ambitious in scope. It aims to develop CAM techniques for electronics, specifically for the small batch sizes of electronic devices which are often needed in a military environment.

The Navy has been slower to pursue automated manufacturing technologies, in part because of the immense product size and often custom-production environment in shipbuilding operations. However, there has been substantial progress in recent years, particularly in robotic welding in shipbuilding.[5]

The Army, Navy, and Air Force ManTech programs are coordinated by a Manufacturing Technology Advisory Group (MTAG), which has representatives from each of the Services, the Pentagon, other Government agencies, and defense-related industries. MTAG and its subcommittees suggest areas for ManTech projects, help avoid duplication of effort, and conduct conferences and demonstrations which help transfer ManTech-developed technologies to industry. In addition, MTAG serves as an informal coordinating and information-gathering body for automation R&D in other Government agencies and industry. Beyond its function for DOD, it is the only established forum in which key representatives from defense-related industry and Government agencies meet regularly to discuss automation R&D. As such, it facilitates some of the informal networking and development of consortia that occurs among Government and industry programmable automation experts. Approximately 200 representatives serve on MTAG and its subcommittees, roughly 80 percent from DOD and the military services, and 10 percent each from other Government agencies and industry.

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[4] L. R. Allen and L. L. Lehn, *Technology Area Description of the Manufacturing Technology Program*, June 30, 1983 (a Pentagon publication).

[5] See, *An Assessment of Maritime Trade and Technology* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, October 1983), and R. Brooks, "Navy ManTech to Focus More on Shipbuilding," *American Metal Market/Metalworking News*, Mar. 12, 1984.

Until fiscal year 1982, DOD conducted a program within ManTech which helped manufacturers pay for implementing new manufacturing technologies, including many of those developed in ManTech projects. This Technology Modernization (TechMod) program—used primarily by the Air Force—has now been relabeled the Industrial Modernization Incentives Program (IMIP), and separated from ManTech funding. (The removal of TechMod from ManTech was one of the reasons for the dip in ManTech funding in fiscal year 1983, along with disagreements described in footnote, p. 314). Some in industry have argued that many of the technologies explored in ManTech are rather esoteric, while those involved in the TechMod or IMIP efforts seem to be more practical.

IMIP is used to supplement cost-reimbursable contracts—procurement agreements with no fixed dollar amount; the firm bills DOD for its materials and services. Such contracts are used for most major procurements at DOD to insulate industry from the unpredictability of building massive weapons systems. Under IMIP, DOD helps pay for installing new manufacturing technology because it expects to reap the benefits downstream in lower reimbursable costs. Although all three services have a mandate to use IMIP, the Air Force continues to be the primary user of the program, with $83 million budgeted in 1984.[6]

Other DOD Programs.—Two other agencies within DOD fund longer term, more basic research efforts related to automation technologies. The Defense Advanced Research Projects Agency (DARPA) has a program in Intelligent Task Automation (ITA), which funds robotics research with both manufacturing and military (i.e., maintenance, logistics, and weapons) uses in mind. Three major initiatives are under way:[7]

- DARPA and the Air Force materials lab are jointly funding a "Systems Integration and Demonstration" project, in which two competing teams of contractors are performing applied R&D that may "lead to quantum jumps" in robotics technology. One team, headed by Honeywell, is attempting to develop a coordinated dual-arm robot—i.e., not two robots operating in sequence, as is already found in industry, but dual arms that can work together much like human arms. Another team, headed by Martin Marietta, is working on a programmable assembly robot which would make extensive use of sensors, enabling it to cope with relatively disordered manufacturing situations such as bins of parts. These projects are 27-month efforts funded at $1.6 million (total) in 1984. DARPA aims to evaluate the research in early 1985 and to continue more intensive work with one of the two teams.
- DARPA budgeted $1.3 million in 1984 for work in sensory control. This includes work on 3-dimensional vision sensing at Carnegie-Mellon University, and ultrasonic imaging at Rockwell International. The latter is intended primarily for nonmanufacturing military needs. For example,

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[6] D. Reeves, staff engineer, IMIP Program, The Pentagon, personal communication, Feb. 10, 1984.

[7] W. Isler, ITA program officer, DARPA, interview, Sept. 2, 1983.

vision systems are of little use in smoke, fog, or darkness on a battlefield, but a sound-based system could construct images based on the way objects reflect sound waves. A third project in this category involves tactile sensing at Case Western Reserve University, where researchers hope to combine conventional touch sensors with what they call a haptic sensor, which would send feedback to the robot controller about the state of "elbow" and "shoulder" joints.

- Finally, $600,000 is budgeted in 1984 for work in advanced mechanical design of robots. This primarily involves developing lightweight, flexible structures (most likely from composite fiber materials), as well as control systems and sensors which would allow controllers to direct the motion of such arms without backlash, and establish the position of flexible arms under various loads.

Aside from these projects in the ITA program, DARPA has been the dominant funder of general artificial intelligence (AI) research, and has proposed an extensive new program called "Strategic Computing" for R&D in AI and advanced computer architectures. Congress has appropriated $50 million for the program in fiscal year 1984, and DARPA plans to spend $600 million total between 1984 and 1988. The program aims for advanced applications of AI techniques (weapons systems in particular) and also includes some development of "supercomputers," machines like the CRAY and CDC Cyber which can process more than 100 million instructions per second. Though this work is not aimed specifically at manufacturing, it may ultimately (in future decades) have some applicability for all computerized systems.

There may be some uses for supercomputers in manufacturing, although currently only CAD and, to some extent, machine vision, need substantially more processing power. Other automation systems may, as their sophistication increases, also require more computer power, but the supercomputer is not likely to be the answer for many of these problems because of its multimillion-dollar price tag and because hierarchical organization of factory computer systems is more likely than reliance on one huge machine. Supercomputers currently cost roughly $5 million to $15 million.

The second DOD agency funding automation research is the Office of Naval Research (ONR), whose manufacturing science program has two components:[8]

- ONR has awarded grants to Stanford, North Carolina State, Purdue, and the University of Maryland (totaling roughly $1.2 million per year) for work in precision engineering. These projects respond to an increasing need for precision in machining and high-quality surfaces, especially for weapons systems and optical instrumentation. There are also a few nonmilitary applications, such as manufacturing of computer disk drives. In general, this research aims to develop machine tools and other devices which can position and shape part surfaces within a tolerance of less than one ten-thousandth of an inch.
- Four other research efforts are under way, at a total funding level of approximately $600,000 per year, in a variety of topics, including 3-dimensional vision, adaptive control of grinding and polishing tools, and automated process planning.

ONR also supports:

- A "special focus program in robotics," spending about $1 million per year total on a variety of topics, and emphasizing "intelligent robot" projects similar to DARPA's.
- Feasibility studies and plans for flexible manufacturing systems, at $800,000 per year.
- Man-machine interaction research, at roughly $500,000 per year. This work, aimed at optimizing computer systems' power and ease of use for humans, includes use of videodisks and multimedia presentations, advanced color graphics,

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[8] E. Glauberson and A. Meyerowitz, ONR, interview, Aug. 10, 1983.

and improvements in ease of use for CAD geometric modeling systems.
- General AI research, at about $2.5 million per year.

The Navy has also begun a robotics program at its Naval Surface Weapons Center in Maryland. That program, budgeted at approximately $4 million per year, is aimed at robotics uses for the military, such as maintenance, testing and support of Navy equipment.[*]

Summary and Conclusions: DOD.—Table 66 summarizes DOD funding of programmable automation R&D. It is clear that DOD supports a substantial amount of R&D efforts related to programmable automation. While DOD's involvement in this area has had significant spinoffs and has led industry to pursue certain aspects of automation, it would be misleading to conclude that DOD's involvement in this area constitutes a focal point in the Federal Government for generic R&D in automation technologies.

First, DOD's projects are mission-oriented in ways that limit their applicability to nondefense manufacturing. The vast majority of ManTech projects, for example, are designed to produce a very specific technology to improve a particular defense manufacturing process. Many of these manufacturing applications, especially those involving ammunition, weapons, or armored vehicles, are unique to DOD. Some ManTech-developed technologies can be modified for commercial use, although there is some question about the effectiveness of DOD's attempts to promote such technology transfer.[9]

Likewise, most of DOD's more basic work, such as that funded by DARPA and ONR, is oriented toward military applications. A DARPA official explained, "We don't have a mandate to be pushing manufacturing . . . You don't have to be a wild-eyed Strangelove to see the possibilities [for use of robots in battlefield support]." In many cases there are commonalities between military and commercial applications of automation technologies: A robot that could navigate a battlefield could also make its way through a cluttered factory; a machine tool that can make very precise parts for weapons systems can also make very precise parts for computer disk drives. Nevertheless, R&D oriented toward military applica-

Table 66.—Summary: DOD R&D in Programmable Automation, Fiscal Year 1984 (in millions)

Manufacturing Technology (ManTech):		
Army, Navy, and Air Force including $20 million for Air Force's ICAM program		$56.0[a]
Defense Advanced Research Projects Agency (DARPA):		
Intelligent Task Automation Program:		
Systems integration and demonstration	1.6	
Sensory control	1.3	
Advanced mechanical design	0.6	
DARPA total		3.5
Office of Naval Research (ONR):		
Manufacturing Science Program:		
Precision engineering	1.2	
Other topics	0.6	
Special focus program in robotics	1.0	
Man-machine interaction	0.5	
Flexible manufacturing systems	0.8	
ONR total		4.1
DOD total		$63.6

[a]Note: The total ManTech budget for fiscal year 1984 is approximately $200 million. Of that total, approximately $56 million funded work in PA.

SOURCE: Department of Defense, Defense Advanced Research Projects Agency, Office of Naval Research.

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[*] Tom McKnight, Naval Surface Weapons Center, personal communication, Feb. 10, 1984.

[9] General Accounting Office report, op. cit.

tions has a much higher payback for defense than for nondefense commercial applications. Transfer of computer-related technologies from DOD to civilian applications is increasingly the exception rather than the rule.

Finally, there is a set of DOD-sponsored activities, such as ICAM and ECAM, which are neither directed toward a very specific defense manufacturing process, nor exclusively oriented toward military applications. These have helped develop substantial automation techniques of fairly generic applicability. However, these programs, like most of the ManTech, DARPA, and ONR projects, tend to apply to, and be useful for, only the most sophisticated of current manufacturers. In a manufacturing sector which has only a small fraction of its machine tools equipped with numerical control, ICAM's hierarchical architecture for an integrated, automated factory may seem to some like science-fiction. Moreover, because of DOD's close relationship with certain supplier firms, technologies developed under programs like ManTech tend to be transferred to the sophisticated aerospace and electronics industries.

In summary, DOD's R&D in programmable automation serves several distinct purposes. It purports to save the Government a substantial amount of money in procurement funds; it makes advances in certain technologies available for commercial exploitation, primarily for high-end users; and it advances the state of automation technology for many military purposes, with some side benefits for nonmilitary industry. DOD has had a significant impact on the directions for automation R&D in civilian industry, and ManTech's MTAG group also serves as a coordination and information-dissemination forum for industry and Government. However, DOD's involvement in this area is not, nor is it intended to be, a general-purpose avenue for widely applicable R&D in programmable automation.

Civilian Agency Programs

Three civilian agencies have substantial research interests related to automation technologies: NBS, NSF, and NASA.

National Bureau of Standards.—Under the auspices of the Department of Commerce, NBS Center for Manufacturing Engineering conducts a considerable amount of automation-related research. As table 67 indicates, NBS' work in automation has grown rapidly over the past few years, to a $7.55 million program in 1984. The budget for automation research is a small part of NBS' total budget of $120 million, and it is also small compared with DOD's budget for automation efforts. NBS has two labs, one in Maryland and another in Colorado, working on issues ranging from fire and construction codes to evaluating computer systems for Federal purchase.

NBS' mandate for involvement in programmable automation R&D is threefold. First, it is intended to be a catalyst for standards-development activities in industry. Standards for computerized devices—in particular for interfaces between such devices—are some of the most prominent issues in the standards area in this decade.

Second, NBS is keeper of the standards for measurement—the agency still keeps the official yardstick and thousands of other official measurement standards in its vault. As part of this role, NBS has also become involved in R&D for such PA devices as programmable "coordinate measuring machines" and other electronic measurement devices that are increasingly used for quality control. NBS must have the capability to certify the accuracy of such machines, and it therefore performs R&D on methods of measurement and methods of using the measurements to improve quality in production. NBS officials believe that the ultimate trend in manufacturing, facilitated by programmable automation, is toward factories which "cannot make a bad part." That

Table 67.—Automation Research, National Bureau of Standards

Year	Appropriation	Reimbursable[a]	Total	Staff (FTE)[b]
1979	$1,150,000	$ 100,000	$1,250,000	12
1980	1,850,000	100,000	1,950,000	19
1981	2,450,000	100,000	2,550,000	25
1982	3,850,000	66,000	3,916,000	39
1983	4,716,000	2,475,000	7,191,000	65
1984 (estimate)	3,850,000	3,700,000	7,550,000	75
1985 (preliminary)	3,900,000	4,800,000	8,700,000	75

[a] R&D contracted by other Federal agencies, primarily the Department of Defense.
[b] Full-time equivalent.

SOURCE: National Bureau of Standards.

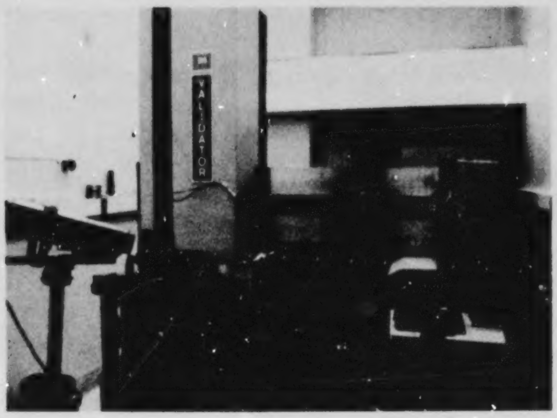

Photo credit: National Bureau of Standards

A coordinate measuring machine undergoes calibration at the National Bureau of Standards

is, with various electronic measurement devices present in the production process and connected electronically to PA control computers, the production line could sense minor variations in dimensions before they became a defect, and the control computers could send a signal to the production machines to correct the variation, or shut down the machine for maintenance.

Third and finally, the Department of Commerce was mandated by Congress in 1965 to recommend standards for the Federal Government's procurement and use of computers and to carry out supporting research in the science and technology of automated data processing. Acting on those mandates, NBS began work in the early 1970's on computer interfaces, including those involved with computer-controlled systems such as robots. Subsequently, this latter work became part of a program on factory automation technologies.[10]

Among the highlights of NBS' automation R&D:

- In 1979, NBS received funding from the Air Force ICAM and other sources to develop a set of standards so that different brands of computer-aided design systems could communicate with one another. The standards, called IGES (Initial Graphic Exchange Standards), specify a common format for geometric data, essentially a lowest common denominator for CAD systems. Typically, the operator of a CAD system can command his/her system to translate a drawing from the proprietary storage format of the CAD manufacturer to the IGES format and record the IGES data on a magnetic disk, which can then be read by a different CAD system and reconverted to the second system's proprietary format.

  IGES was released in a preliminary form in 1980, and was adopted by CAD manufacturers in record time, according to NBS researchers. They speculate that the reason for this rapidity was that the CAD industry was "hurting" for a standard—that is, customer complaints and dissatisfaction about the inability to exchange drawings between CAD systems hurt sales and limited possible applications.[11]

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[10] Robert Hocken, chief, Automated Production Technology Division, NBS, personal communication, Oct. 5, 1983.

[11] Robert Hocken, Chief, Automated Production Technology Division, NBS; OTA Automation Technology Workshop. A second and third version of IGES have been launched, building

- With funding assistance from the Air Force and Navy, NBS researchers are designing and assembling an Automated Manufacturing Research Facility (AMRF) to serve as a laboratory for various kinds of CIM R&D. The facility is being constructed in a portion of the NBS machining shop in Gaithersburg, Md., which produces roughly $2.5 million worth of parts annually for use by NBS researchers. PA equipment manufacturers have donated several key pieces of equipment for the project that are, in some cases, more advanced than commercially available products. In this project, as in others in NBS automation R&D efforts, industry has loaned technical staff to work at NBS for a fixed period of time. In return, the firm gets firsthand knowledge of NBS R&D and enhanced opportunities to transfer technologies developed at NBS to their own labs. The AMRF is constructed from "off-the-shelf" hardware (i.e., the machine tools, robots, and other devices are bought from or donated by manufacturers from their product lines) because NBS argues that it is software and interface systems, not hardware, which need to be developed further to enhance possibilities for automated manufacturing. In addition, NBS officials working with the AMRF are emphasizing the possible applications of automated technology for the large number of small machine shops which fabricate parts in batches too small for conventional automation, but large enough to enable the use of PA.*
- NBS researchers also pursue a wide range of R&D related to specific PA technologies, including important work in the use of structured light for 3-D vision perception, simulation of factory operations, and control systems for automated factories.

NBS staffers also contribute to standards efforts by serving on and helping to coordinate the many private sector standards committees working on automation issues.

National Science Foundation.—NSF also plays a significant role in funding of automation research. Because of its interdisciplinary nature, several different parts of the agency contribute to this work. Table 68 highlights some of the programs within NSF which fund PA research. NSF has tried to rationalize and coordinate its funding in this area by establishing in 1981 a Coordinating Committee on Research on Intelligent Robotic Systems, and by issuing in 1983 a "Program Announcement in Intelligent Robotics Systems and Automated Manufacturing," which sets forth the possible avenues for funding.

The Production Research Program in the Engineering Directorate* is directly focused on programmable automation for discrete manufacturing. This program has grown rapidly in the past 5 years—from $2.3 million in 1980 to $4.6 million in 1984—but is still relatively small. Although exact figures are not available, NSF officials estimate that the funding for PA research from all programs at NSF might be 1.5-2 times as much as the budget of Production Research, or roughly $7 to $9 million in 1984. In fiscal year 1983, the Production Research Program included 17 projects in CAD, 47 projects in various aspects of computer-aided manufacturing technologies, and 11 projects in computer-aided testing. Production research, in collaboration with NSF's Industry-University Cooperative Research Program, also provided seed money for two new industry-university research centers, one in robotics at the University of Rhode Island, and one in materials handling at Georgia Tech.**

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on the initial version, and makers of 30 CAD systems have announced that they subscribe to IGES. ("IGES Version Accommodates Modelers," *American Metal Market/Metalworking News*, Dec. 13, 1982).

*OTA site visits, AMRF/NBS, Apr. 18, 1983, and Nov. 14, 1983.

*NSF is divided into six directorates (administration; astronomical, atmospheric, earth, and ocean sciences; biological, behavioral, and social sciences; engineering; mathematical and physical sciences; and scientific, technological, and international affairs). Each directorate has four or five divisions.

**For example, General Electric (GE) reported that its recently released "BinVision" system was based on machine vision research conducted at the University of Rhode Island. GE is one of 27 companies, in addition to NSF, which fund the center. "Vision Sensors Expanding Industrial Robot Flexibility," *Aviation Week and Space Technology*, May 30, 1983, p. 139.

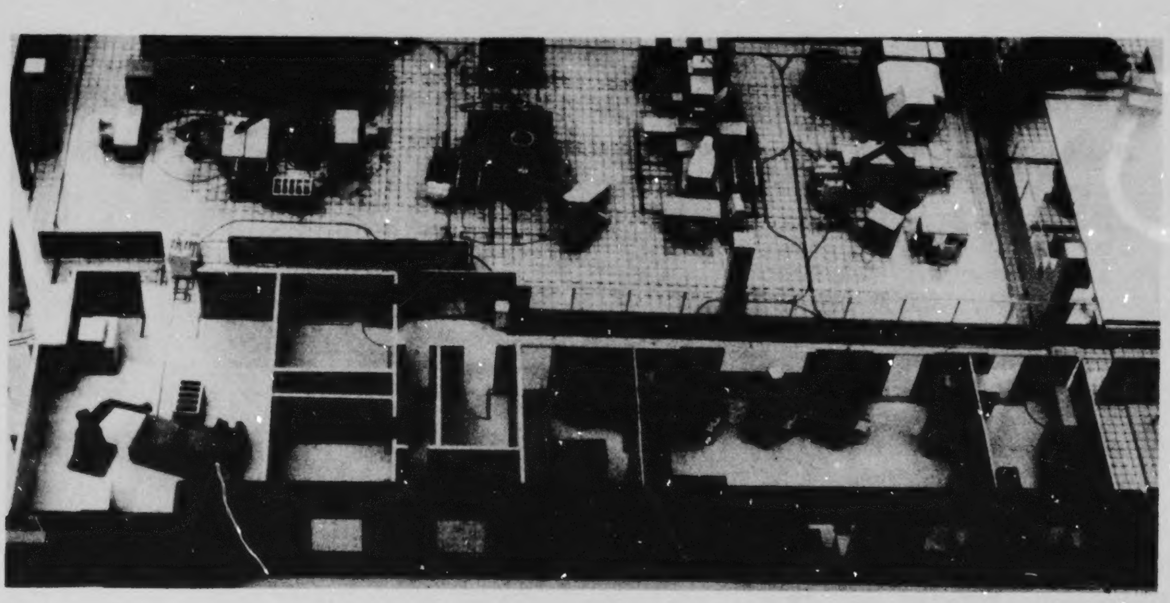

Photo credit: National Bureau of Standards

Scale model of the Automated Manufacturing Research Facility being constructed at the National Bureau of Standards in Gaithersburg, Md.

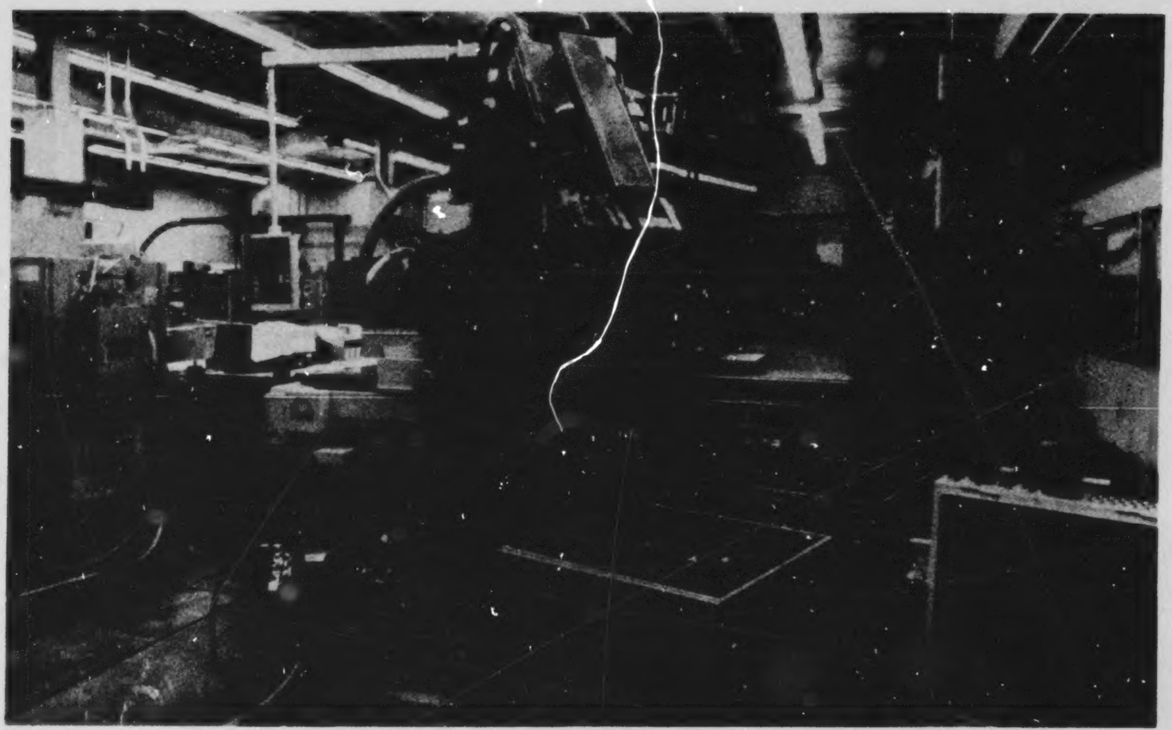

Photo credit: National Bureau of Standards

A robot, part of the Automated Manufacturing Research Facility, grasps metal "blanks" to be machined from trays which are delivered by automatic guided vehicles

Table 68.—Selected NSF Programs Which Fund Automation-Related Research

Program	Aspects of automation
Automation, bioengineering, and sensing systems	Touch and vision sensors, control systems
Computer engineering	Robot programing languages, computer architectures, human-computer interface
Electrical and optical communications	Communication networks, integrated optics for vision sensors
Industry/university cooperative research	Seed funds for cooperative industry/university research centers
Mechanical systems	Mechanical aspects of robots, CAD
Production research	All aspects of factory automation for discrete manufacturing
Quantum electronics, waves and beams	Sensors and processes using lasers
Small business innovation	Incentive grants for research in small high technology firms
Solid state and microstructure engineering	Fabrication of miniature devices for sensing and control
Systems theory and operation research	Large-scale systems control, scheduling, organization

SOURCE: National Science Foundation, "Program Announcement in Intelligent Robotics Systems and Automated Manufacturing," No. 3145-0056, 1983.

A new initiative for fiscal year 1985 aims to provide $10 million as seed funds to establish 5-10 centers for cross-disciplinary engineering research. It is likely that one or more of these centers will be focused on automation.

Other programs at NSF which fund work related to PA include Automation, Bioengineering, and Sensing Systems; Computer Engineering; Electrical and Optical Communications; Mechanical Systems; and Systems Theory and Operation Research. In addition, programs in social sciences and policy analysis include a small amount of work on the social effects of new technologies such as programmable automation.

The primary funding machanism at NSF is grants made in response to unsolicited research proposals, which are evaluated by NSF staff and external reviewers. Few if any strings are attached regarding the nature or direction of the work. However, NSF is also mandated to encourage transfer of science and technology to industry, and several programs which fund PA research take an active role in facilitating such transfer. Three staff members from the Industrial Science and Technological Innovation Division, for example, in collaboration with eight other experts, recently studied the diffusion process and called for more coherent and supportive government policy in this area:[11]

> Taking advantage of advanced manufacturing capabilities is a process which will require considerably more, and more systematic, attention to the phenomenon of deployment than has heretofore been generally in evidence in U.S. industry.

This and related Government policy issues will be examined in Chapter 10.

National Aeronautics and Space Administration.—NASA pursues three general types of programmable automation R&D. They are summarized in table 69.

The first is robotics and teleoperator research to develop manipulators for applications on space missions. Near-term NASA uses will involve teleoperators rather than robots. Their movements will be controlled more or less directly by a human, who is either in space or on the ground. For example, the Space Shuttle's well-known Remote Manipulator System, which reaches into the shuttle's cargo bay to extract and manipulate satellites, is controlled by the shuttle's flight crew. Because of the relatively direct human control of the teleoperator, human factors research to develop the most effective combinations of man and machine is very prominent in the program. NASA researchers expect people to remain in direct control of these devices for some time because of the complexity of the tasks.

The robotics and teleoperator work is now focused on a "Remote Orbital Servicing System," an unmanned space vehicle that would be capable of servicing satellites by ground

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[11] L. G. Tornatzky, W. A. Hetzner, and J. D. Eveland (National Science Foundation, Division of Industrial Science and Technological Innovation), "Fostering the Use of Advanced Manufacturing Technology," *Technology Review*, in press, 1984.

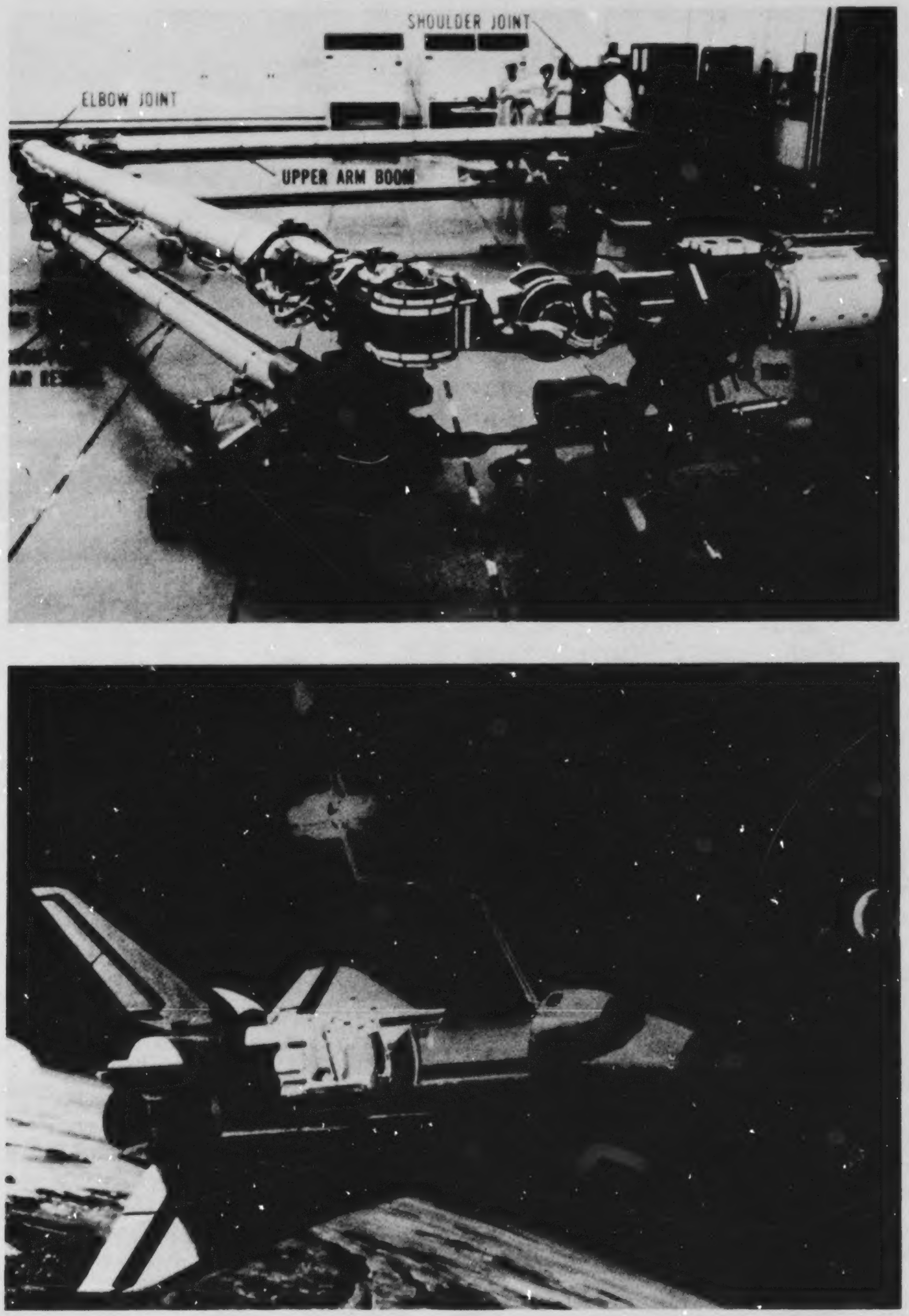
SHOULDER JOINT
ELBOW JOINT
UPPER ARM BOOM

Photo credit: National Aeronautics and Space Administration

Top, the space shuttle's manipulator arm in a laboratory. Bottom, an artist's conception of the manipulator as it deploys a satellite from the shuttle

Table 69.—NASA Automation Research (dollars in thousands)

	Fiscal year					
	1980	1981	1982	1983	1984	1985 (prelim.)
Automation research program:						
Robotics/teleoperators	$ 538	$ 245	$ 600	$1,600	$1,600	$1,600
Artificial intelligence/computer-aided planning	1,048	1,017	1,065	2,000	2,000	2,000
Integrated program for aerospace vehicle design (IPAD)[a]	NA	5,000	2,100	2,300	2,300	2,500
Total	NA	6,262	3,765	5,900	5,900	6,100

NA—Not available.

Note: Figures do not include salaries of NASA personnel, which are budgeted separately.

[a] IPAD figures include NASA funds only. The Navy also contributes to the program, and plans to spend an additional $2 million for IPAD in 1985.

SOURCE: National Aeronautics and Space Administration.

control commands to its manipulator arm.[13] For the future, NASA is exploring machine vision and AI systems which would allow a servicing vehicle to conduct repairs somewhat autonomously. Most of this research is conducted in-house at the Jet Propulsion Laboratory and at Langley Research Center. NASA also supports research work at the University of Illinois and Stanford University.

The second major area of NASA's involvement in programmable automation R&D is the development of an advanced computer-aided planning system called "Deviser," developed at the Jet Propulsion Laboratory in response to the complicated and sometimes conflicting needs for scheduling NASA's recent unmanned scientific missions (the Voyager series). The Voyager craft is radioed signals to direct its trajectory, aim its telescopes and cameras, and manipulate other scientific equipment. Dozens of NASA scientists request the attention of the satellite for particular experiments, and according to one NASA researcher, it takes hundreds of man-years to develop efficient plans and tell the spacecraft what to do.[14] Deviser uses sophisticated programing techniques to juggle the capabilities of the satellite and the demands of the scientists, resulting in an order-of-magnitude increase in productivity, according to NASA officials.

The final area of NASA's involvement in automation R&D is an effort called Integrated Programs for Aerospace Vehicle Design (IPAD), which was begun in 1976. It is a joint NASA/industry program whose goal is to integrate computer-aided design and engineering systems used in the design of aerospace vehicles, and to link them with powerful software systems which could help manage the tremendous amount of information involved in designing such a complex product. Boeing Commercial Airplane Co. is the prime contractor for the IPAD R&D effort.

Other Federal Agencies.—Several other Federal agencies fund small R&D efforts, primarily in robotics for nonmanufacturing applications. These include the Department of Energy, which is interested in the use of robots to service nuclear power facilities. The Department of Agriculture has also recently been investigating use of robotics for various agricultural applications. The Department of Transportation's Transportation Systems Center has conducted R&D in robotics for motor vehicle manufacture in the past, but the current administration views such work as the responsibility of industry.

Summary and Conclusions—Civilian Agencies.—Table 70 summarizes the programmable automation R&D supported or conducted by Federal civilian agencies. The three Federal agencies primarily concerned with PA each have very different roles. NBS plays a unique role in three respects:

1. Support of standards efforts for PA devices, and relevant research to determine

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[13] A. J. Meintel, Jr. and R. L. Larsen, "NASA Research in Teleoperation and Robotics," paper presented at the Society of Photo-Optical Instrumentation Engineers Conference, Aug. 23-27, 1982.

[14] R. L. Larsen, Computer Science and Electronics Office, NASA, personal communication, Aug. 25, 1983.

Table 70.—Summary: Federal Civilian Agency R&D in Programmable Automation, Fiscal Year 1984 (in millions)

National Bureau of Standards (at NBS labs in Gaithersburg, Md.):		
NBS-funded work	3.85	
Work sponsored by other Federal agencies (primarily Navy and Air Force funding for automated manufacturing research facility)	3.70[a]	
NBS Total		3.85
National Aeronautics and Space Administration (approximately two-thirds is conducted in NASA's in-house labs, and one-third is grants/contracts to non-NASA labs):		
Teleoperator research	1.60	
Artificial intelligence/computer-aided planning	2.00	
IPAD	2.30	
IPAD work funded by Navy	1.875[a]	
NASA total		5.90
National Science Foundation (all grants/contracts to universities and nonprofit labs):		
Production Research Program	4.60	
Other NSF grants centrally concerned with PA from a variety of programs (estimate)	2.30-4.60	
NSF total		6.90-9.20
Total for civilian agencies		16.65-18.95

[a] Not included in civilian total.

SOURCE: National Bureau of Standards, National Aeronautics and Space Administration, National Science Foundation.

how best to construct standards, particularly for interfaces between PA devices.

2. Development of the AMRF, perhaps the only full-scale test bed for integrated PA research using some of the most advanced technologies that have been developed.
3. Serving as a resource to other Federal agencies and to the private sector on a range of issues related to PA.

NSF is the Government's only avenue for support of generic research on a broad range of subjects related to PA, although available funds are limited. Hence, NSF supports longer term research in many areas which might not receive funding from mission-oriented agencies such as DOD or NASA. In addition, NSF funds provide crucial support to universities for building the foundation of automation R&D—maintaining technical expertise in the universities and helping to train new technical experts through students' involvement in research work.

NASA's aims for automation R&D are complex and specialized. However, these efforts could have substantial spinoffs in the longer term.

Industry-Funded R&D

The amount of money and effort which industry as a whole spends on programmable automation R&D is hard to gauge. Statistics about R&D tend to be either protected by proprietary concerns or muddled by inconsistent definitions of R&D and industry classifications. With increasing Federal tax incentives for R&D activities, many firms seem to have broadened the set of activities and expenditures to which they attach the label, "R&D."[18]

Nevertheless, several agencies and research firms have made estimates of R&D expenditures in various classes of industry, including computers, and mechanical manufacturing (see table 71). No similar effort has been undertaken for PA vendors as a group. However, examinations of R&D in information technology-related industries tend to reveal a pattern of fairly consistent and comparatively high spending for R&D as a proportion of gross sales. By combining estimates of gross sales in automation industries with industry ana-

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[18] National Science Foundation, *Science Resources Studies Highlights*, Sept. 9, 1982.

Table 71.—Company R&D Expenditures as a Proportion of Sales, By Industry

	NSF[a]	*Business Week*[b]		
	1980	1980	1981	1982
Machinery	4.8			
Office, computing, accounting	10.0	4.3-6.4	5.0-6.4	5.1-7.2
Other machinery, except electrical	2.3	1.6	1.9	2.6
Electrical equipment	3.9	2.8	2.9	2.8
Radio and TV receiving equipment	1.6			
Communication equipment	5.2			
Motor vehicles	4.3	4.0	3.7	4.0
Motor vehicles parts and equipment		1.9	2.0	2.3

[a] National Science Foundation, "Research and Development in Industry, 1980." Data are based on a survey of approximately 11,500 companies, conducted by the Bureau of the Census.

[b] *Business Week*, "R&D Scoreboard," July 6, 1981, July 5, 1982, and June 20, 1983. Data are based on the amount of R&D spending reported to the Securities and Exchange Commission on Form 10-K. Companies included are those reporting sales for the year of $35 million or more and R&D expenses amounting to at least $1 million or at least 1 percent of sales. Industry classifications used by *Business Week* are similar, but not identical to those used by NSF. Hence the two sets of data are not strictly comparable.

lysts' assessment of the percentage of gross sales spent on R&D, one can arrive at an estimated range for automation industry spending on R&D (table 72).

Such estimates are possible only for the programmable automation technologies that comprise an industry—notably CAD, robotics, and machine tools. Table 72 shows that R&D spending in just these three industries was approximately $264 million to $400 million in 1983. This is roughly 3 to 5 times as much as the approximately $80 million spent by Federal agencies for the whole range of programmable automation R&D. PA-industry spending for R&D has increased rapidly in the past few years, in parallel with high industry growth rates particularly for robots and CAD. (See ch. 7 for further detail.) However, robots industry analysts expect the proportion of gross sales spent on R&D in that industry to decline from an estimated 12 to 18 percent to 10 to 12 percent as sales in the industry accelerate.

Only a few companies conduct substantial work in more long-range basic or applied PA research, as opposed to relatively short-term product development (although it should be noted that such product developments provide important feedback to more long-term research efforts regarding productive directions for R&D). These more long-range efforts include IBM's research, primarily in robotics and sensing technologies; GE's work in robotics, sensing, computerized controllers, and CIM; GM's research in robotics; Cincinnati Milacron's efforts in robotics, machine tools, automated materials handling, and flexible manufacturing systems; Unimation's (now owned by Westinghouse) robotics research; and Computervision's CAD explorations. It

Table 72.—Estimated R&D Expenditures in PA Industries, 1983 (in millions)

	Industry sales	Estimated percent of sales spent on R&D	Estimated level of R&D spending
CAD	$1,600	12-18	$192-$288
Robots	$ 235	12-18	$ 28-$ 42
Machine tools	$1,750[a]	2.5-4.0	$ 44-$ 70
Total			$264-$400

[a] National Machine Tool Builder's Association. Note that the U.S. machine tool industry has been experiencing dramatic changes in level of sales. For example, shipments in 1982 totaled $3.7 million, while those in 1981 totaled $5.1 million.

SOURCE: Interviews and compilation of material from industry analysts.

should be noted that users of automation technologies, particularly large firms such as GM and GE, are playing important roles in R&D and have in many cases become vendors themselves (see ch. 7).

In addition, some of the large consulting and research firms have played key roles in development of programmable automation technologies. SRI International has been a pioneer in machine vision and robotics research; Draper Laboratories has conducted robot and FMS research, and consults with industry on implementation of automation systems; other "think tanks" such as Battelle Laboratorie and Arthur D. Little have played key roles in both research on the technologies and assisting in implementation.

There is also evidence of more extensive interaction in the past few years between industry and academia on manufacturing automation research. Many universities have set up cooperative research centers in which firms contribute funds to support manufacturing-related research efforts. These centers vary in the extent to which industry has a say in the research agenda and control over the results.

One kind of university-industry cooperative program is the Manufacturing Engineering Applications Center (MEAC) at the Worcester Polytechnic Institute (WPI). Here, professors and students work with staff from companies to develop specific applications of automated equipment. Emhart Corp. helped to establish and was the first to work with WPI on such a project. For Emhart, the goals of the program were to obtain:[16]

1. assistance in conducting practical, short-term applications research that would adhere to industrial time lines and result in completed projects delivered to Emhart within 1 year;
2. a situation that would promote technology transfer—(i.e., that would help the firms receiving the systems to understand the development processes and the operations of the systems themselves); and
3. provision of laboratory and office space on the campus for Emhart engineers to enable them to work in an environment free from production pressures and responsibilities.

MEAC's liaison with Emhart resulted in several applications developed for the company's factories, and MEAC has now expanded to include two other firms.

Another form of industry-university effort is the Industrial Affiliates program at Carnegie-Mellon University's Robotics Institute. Various industrial sponsors (Westinghouse is one of the largest) contribute more than $2 million per year.[17] The institute includes labs in flexible assembly, flexible manufacturing, intelligent systems, vision, mobile robots, smart sensors, automatic programing, and social impacts analysis. The sponsors, however, do not have control over research agendas, but rather have priority in obtaining the research results and are entitled to limited consulting service from the Institute faculty. This more limited impact on research agendas is generally the norm at top engineering schools with similar programs, such as MIT and Stanford.

Industry-university cooperative research centers are spreading rapidly. Though it is not feasible to list all of them, other universities which undertake PA research in cooperation with industries include the University of Rhode Island, Georgia Institute of Technology (both discussed earlier in the NSF section), Purdue, the University of Florida, and the University of Maryland.*

One of the most dramatic industry moves to support university PA research was IBM's donation of $50 million in cash and equipment in 1983 to support manufacturing education. The grants were given to about two dozen schools—$10 million was allocated to universities to implement new manufacturing-systems curricula at the master's degree level, while $40 million in CAD and other computer equipment was donated to support research and education in manufacturing using state-of-the-art tools.

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[16] OTA Education and Training case study.

[17] The Robotics Institute, Carnegie-Mellon University, "The Industrial Affiliates Program."

*Others in the growing list include the University of Michigan, Brigham Young University, and the University of Utah.

Finally, there are several interfirm cooperative research efforts relevant to programmable automation.* CAM-I, based in Arlington, Tex., has eight active research groups in which members pool funds to support research in areas of interest. The groups are Sculptured Surfaces, Process Planning, Geometric Modeling, Advanced NC, Factory Management, Electronics Automation, Quality Assurance, and Robotics Software. CAM-I was a spinoff from DOD's early efforts to develop NC machine tools. Now independent of DOD, the membership of CAM-I includes American and foreign companies as well as some universities and Government agencies. The members pay a fee for each of the seven research groups in which they choose to participate, ranging from $8,000 to $10,000.** In return they have a voice in the direction of research and receive copies of all the reports, documentation, and software produced in the research group. CAM-I does not actually conduct the research inhouse, but contracts for research efforts in industry and private laboratories.

Microelectronics and Computer Corp. (MCC) is a controversial collective research effort formed in 1982, and aimed at research on advanced semiconductor and computer architecture technologies. Based in Austin, Tex., MCC performs much of its research in-house with about 50 researchers. It has a $75 million annual budget contributed by 13 medium-sized electronics manufacturers. Another group, the Semiconductor Research Corp., consists of 19 electronics firms. It has already granted more than $8 million to support university research that would advance the technology of integrated circuit manufacture.[18]

The issue of cooperative research efforts has been hotly debated over the past 2 to 3 years. In some cases, industry executives have argued that the ability of foreign companies, particularly in Japan, to form R&D collectives (sometimes with government assistance) gives them an unfair advantage over American firms. Often, the perceptions of what antitrust law will permit do not mesh with the law itself. In general, collective research is permitted under current U.S. law, though there may be legal difficulties if, for example, the firms involved are those which dominate an industry or if they wish to restrict access to the results of the effort.[19]

The issue of what constitutes an appropriate area for collective R&D is not at all clear. Some industry observers argue that the advantages of collective R&D are, by and large, illusory—while Japanese cultural habits encourage group efforts of all kinds, American companies perform better in mutual competition.[20]

In any case, there seem to be at least three advantages in principle to some collective R&D endeavors: First, a collective effort may be useful if there are high costs and risks involved, with uncertain and long-term paybacks. Certain problems in programmable automation fit this description. R&D in computer-integrated manufacturing, for example, requires an immense investment in equipment and tremendous labor costs because of the complexity of running and modifying such a system. Second, CIM is clearly an interdisciplinary problem, and a collective effort could be useful in bringing together expertise from, for example, a machine tool manufacturer, a computer manufacturer, a materials handling system manufacturer, and so forth. And finally, collective research efforts can afford smaller companies the opportunity to enter or stay in a market where R&D costs would be prohibitively high if they were conducting such work independently. Nevertheless, a great deal of R&D in programmable automation is taking place without collective efforts, and promotion of such efforts may not be necessary in this area.*

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*Some of the consortia which pursue integrated manufacturing R&D came together, either formally or informally, through DOD. For example, several parts of the Air Force's ICAM program brought together a variety of industry contractors and subcontractors.

**CAM-I brochures.

[18] "High-Tech Companies Team Up in the R&D Race," *Business Week*, Aug. 15, 1983, pp. 94-95.

[19] U.S. Department of Justice, Antitrust Division, *Antitrust Guide Concerning Research Joint Ventures* (Washington, D.C.: Department of Justice, November 1980). OTA's forthcoming study, *Information Technology Research and Development*, will discuss joint ventures in R&D in more detail.

[20] OTA Automation Technology Workshop, May 29, 1983.

Other Sources of Funding for R&D

In addition to the Federal Government and industry, a small portion of R&D funds are provided by State and local governments, nonprofit organizations or foundations, and by universities. Often this funding is in conjunction with efforts to set up local high-technology centers, for the purpose of attracting or revitalizing local industry, or for retraining local workers. Such centers are proliferating rapidly throughout the country.

Michigan, for example, has established an "Industrial Technology Institute" to help ease the State's adoption of advanced manufacturing technologies. The institute has received grants from the Dow Foundation ($10 million), the Michigan Economic Development Authority ($17.5 million), and the Kellogg Foundation ($40 million).[31] The State of Rhode Island has proposed "Industrial Greenhouses" to capitalize, in part, on robotics technology developed at the University of Rhode Island. Even the State of Hawaii has made a $50,000 grant to the University of Hawaii to launch a Pacific International Center for High Technology Research.[32]

These are only a few examples of the many local centers which have been proposed or established. The proliferation of such centers is evidence that many States and regions believe that computerized manufacturing automation technologies are "the wave of the future." However, only a finite number of such centers for robotics, for example, can operate effectively. And establishing such a center always involves tradeoffs with other local priorities.*

---

*Further, current research efforts in automated manufacturing, for example at NBS and GE, suggest that the scale of effort required for integrated manufacturing research is not as massive as that in, for example, the development of new aircraft engines. Such initiatives may require R&D expenditures on the order of $1 billion. (See, for example, R. Witkin, "7 Companies to Spend $1 Billion on Jet Engine," *The New York Times*, Nov. 1, 1983, p. D1.)

[31] "Smith Heads High-tech Group Pushing Advanced Factories," *Automotive News*, July 11, 1983.

[32] A. A. Smyser, "Low Performance on Hi-Tech," *Honolulu Star-Bulletin*, Aug. 9, 1983. This decision was relatively controversial in Hawaii. State Senator Mary George lambasted the program, asking, "What are we doing in this world-class competition when we are basically a sand-lot team?"

*For more information on this and related issues, see the recent OTA studies, *Census of State Government Initiatives for High-Technology Industrial Development* (May 1983) and *Encouraging High-Technology Development* (February 1984). Both of the aforementioned are background papers for the forthcoming OTA study, *Technology, Innovation, and Regional Economic Development.*

International Comparisons in R&D

Foreign R&D efforts in PA are tremendously varied. This analysis will elucidate certain themes in the content of foreign R&D, and point out strengths in particular foreign research programs. Institutional issues concerning foreign R&D (e.g., research cooperatives and government R&D support), are addressed in the International Comparisons chapter (ch. 9).

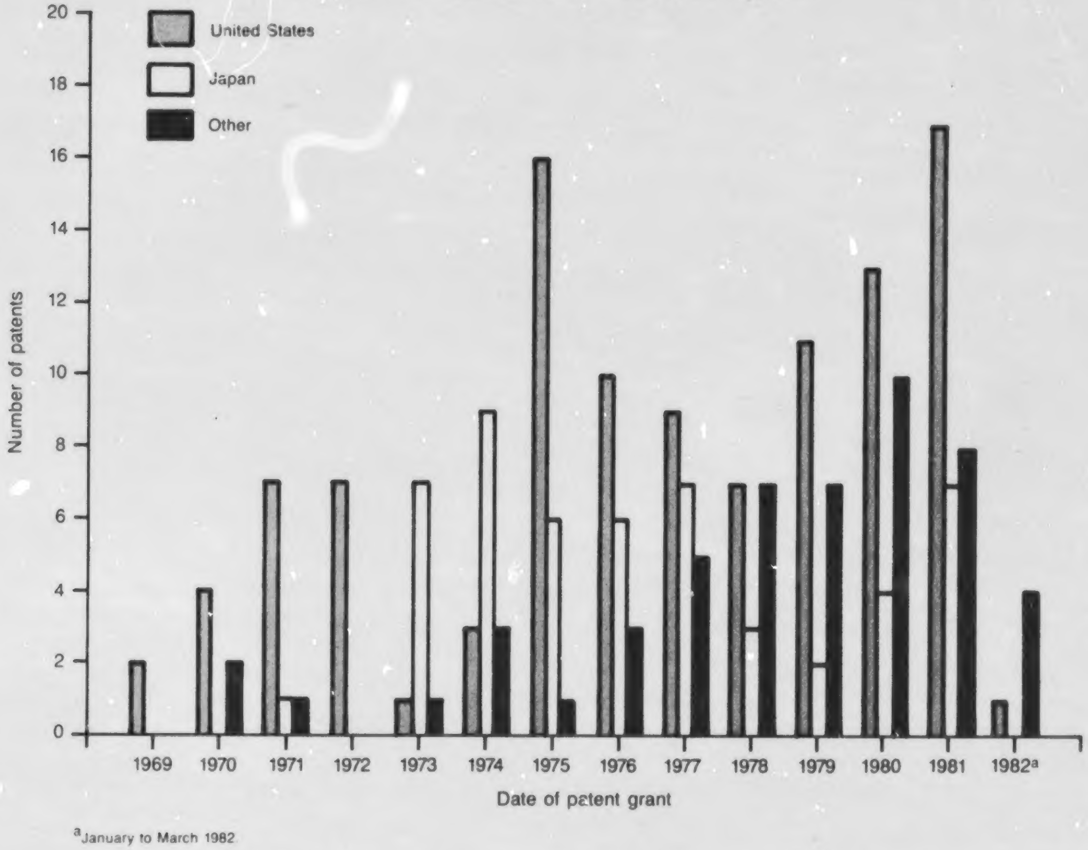
In order to analyze international R&D, the level of R&D must be treated separately from the level of application of automation technologies. Hence, while certain other countries exceed the United States in use of PA (see chs. 7 and 9) the vast majority of R&D in programmable automation has taken place in the United States. Japan, West Germany, and Sweden, and to a lesser extent France and

Great Britain, have also become important contributors to automation R&D.

One indicator of the relative contributions of different countries to this technology is the number of patents that residents of each country hold. Patents are not a good index of quality of innovation, nor is it assured that foreign innovations that are not marketed here will be patented in the United States (and therefore available as statistics). However, it may nevertheless be instructive to examine the international distribution of U.S. patents. A 1982 study by the U.S. Patent and Trademark Office showed that U.S. residents hold 51 percent of the U.S. patents for robotics, while the Japanese hold 24.5 percent and residents of other countries (largely West Germany, Sweden, France, and Italy) hold the remainder.[23] Figure 38 shows that U.S. dominance in U.S. robotics patents has been erratic but generally strong.

Moreover, automation technology researchers believe, almost unanimously, that the United States is still in the lead or at least equivalent in level of sophistication in virtually all areas of R&D.[24] A typical comment

Figure 38.—Patent Activity by Country Comparison



aJanuary to March 1982

SOURCE: U.S. Patent and Trademark Office, *Industrial Robots: A Survey of Foreign and Domestic U.S. Patents*, August 1982.

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[23] U.S. Patent and Trademark Office, U.S. Department of Commerce, *Industrial Robots: A Survey of Foreign and Domestic U.S. Patents* (Washington, D.C.: Department of Commerce, August 1982).

[24] OTA Automation Technology Workshop, various personal communications.

is this one from an Army technical officer's Japan trip report: "No equipment was seen during the trip that lead (sic) me to believe the Japanese had any sort of technology edge in the robotics area. In fact, much of their recent work in the machine vision area owes a technology debt to R&D performed by such firms as SRI International."[25] This position is often voiced defensively by U.S. technology experts as foreign government efforts, particularly in Japan, have received increased attention.

Japan.—It is by now a cliche that Japan's fundamental strength has been in applying technologies, rather than in more fundamental innovations. There is a moderate consensus on this point, though there is not a consensus on its significance. Some argue that it is sensible for a country to emphasize applications when another country (the United States) is a strong leader in technical areas. In any case, the Japanese have taken steps to bolster their capacity in areas which they have not heretofore emphasized, including software and more fundamental research. A 1982 Japanese White Paper explains:[26]

> . . . It has also been said that Japanese technology has for the most part been introduced from other industrially advanced nations, and that only a few innovations have been created by Japanese scientists and engineers.
>
> Meanwhile, prevailing situations seem to suggest that the once active creation of new technologies by foreign countries has lost its glamour at the moment; in addition, there are many instances in which foreign countries and business corporations appear reluctant, as a strategic measure, to transfer the limited scope of remaining technological know-how to Japan. Given these circumstances, it has become absolutely necessary for Japan to develop creative technologies on her own if she is to maintain her economic viability among the world's industrially advanced nations.

The Japanese plan for bolstering innovative capacity involves establishing long-range R&D efforts, setting up various new programs for researchers, promoting public understanding of the issue, and pursuing active international cooperation in science and technology development.

This plan is one of several wide-ranging efforts that the Japanese have announced in the past few years. Others include development plans for the "fifth generation" computer project and the "Flexible Machining Complex Equipped with Laser (FMC/laser)." The Japanese seem to have a propensity for establishing plans and goals which far exceeds that of many other countries, even those such as the United States whose research in these areas is extensive. This has led one U.S. computer expert to complain, "We're being out-brochured."[27]

Many of these ambitious efforts have not yet shown substantial results. The FMC/laser project is a good example. Begun in 1977 with a budget of approximately $6 million a year in government money and significant private-sector support, the project was designed to produce an advanced, "metamorphic" (i.e., easily changed) machining cell which would use a laser both for cutting metal and for measurement. However, the result of the project is neither advanced nor flexible, according to an NBS official, and the use of a laser was more a political decision than a technical one (i.e., it brought the electrical engineering community in Japan into the project).

> The program has broken little new technical ground. It has had to retreat from the most ambitious technical goals of the program. When asked about these apparent technical failures, the MITI people responded that this did not matter, that the true goal of the program was to create a national team to work on automated manufacturing and that this goal was accomplished.[28]

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[25] C. S. Shoemaker, Special Projects Office, U.S. Army Human Engineering Laboratory, "OCONUS Trip Report," dates of travel: Oct. 4-17, 1981. Many similar sentiments were expressed at the OTA Automation Technology Workshop, May 29, 1983.

[26] "In Pursuit of Creativity in Science and Technology: Outline of White Paper on Science and Technology 1982," *Science and Technology in Japan*, vol. 2, Apr. 1, 1983, pp. 18-23.

[27] Neil Lincoln, Control Data Corp., OTA Workshop on Advanced Computer Architecture, July 14, 1983.

[28] J. A. Simpson, director, Center for Manufacturing Engineering, NBS, "FMC/Laser vs. AMRF: A Comparison," speech to Manufacturing Studies Board of the National Academy of Engineering, 1982. Simpson arranged an exchange between the

The product of the FMC/laser project turned out to be considerably simpler than its goals implied, somewhat like a mass-production line which can be easily reconfigured. Whether or not this was intended, the notion of simplicity seems to be an underlying theme in several Japanese automation products and development efforts. Japanese FMSs, for example, tend to be substantially smaller and simpler, without the complex recovery methods for worn tools and bypass-loops in material-handling tracks which characterize U.S. designs. An engineer for Niigata Engineering Co. explained to one reporter, "Complex systems are prone to failures . . . we don't want our systems to stop, not more than a few times a year."[29]

Further, Japanese FMSs seem to place lower emphasis on the goal of completely unmanned production, instead replacing "some work slots where logical"[30] and leaving other jobs for human workers. These principles may seem to contradict reports of unmanned production at certain Japanese factories, particularly the well-known Fanuc factory near Mt. Fuji. However, even this plant, upon closer examination, reveals a reliance upon human workers and relatively simple processes. At night, NC machining takes place without direct human supervision, although a worker monitors the production floor from a control room. Workers are still key features of the production equipment during the day. Each NC machine tool has an operator who is primarily responsible for its performance.[31]

The Japanese are very active in R&D on industrial robots. A recent JIRA survey notes that the number of government and university robot R&D facilities in Japan has doubled over the past 3 years.[32] The number of robot research facilities in Japan, according to JIRA, exceeds the number existing in the United States, but such a claim has not been verified.[33] Until 1982, private industry had shouldered the major responsibility for Japanese R&D in the robotics field. According to a JIRA survey in 1979, over two-thirds of robot manufacturers had conducted some form of in-house robot research. Private research has concentrated mainly on application—i.e., on speed, miniaturization, computer control, weight reduction, and development of interchangeable robots.[34]

Other International Comparisons.—For historical, social and political reasons, countries have different strengths and weaknesses in R&D areas. There are many areas in which the United States is a strong international leader. These include:

- Long-range basic science research, where the U.S. university system is unmatched in size and effectiveness.
- Artificial intelligence, where the most important centers for AI work have long been in the United States (MIT, Stanford, CMU, and SRI International; the University of Edinburgh, Scotland, is also a historically important center but somewhat less prominent today).
- Software as a whole, which appears to stem from American dominance of the computer field. CAD and computer graphics in particular are American strengths. The United Kingdom recently has developed a very good reputation and

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FMC/laser project and NBS' AMRF staff. Japan's MITI has announced that the product of the FMC/laser project will be made part of a new test plant for computerized, unmanned operation, scheduled to be completed in 1984. (M. Inaba, "MITI Builds Laser-equipped Flexible Manufacturing System," *American Metal Market/Metalworking News*, Nov. 21, 1983.)

[29] M. Inaba, "In FMS, Simplicity Governs: Japan's Philosophy of Design Differs Somewhat From the U.S. Approach," *American Metal Market/Metalworking News, Japanese Machine Tools Supplement*, July 11, 1983.

[30] Ibid.

[31] See N. Usui, "Untended Machines Build Machines," *American Machinist*, June 1982, pp. 142-145. There have been conflicting reports on the number of workers at the plant. In addition, several other portions of the plant use human workers extensively, notably for assembly.

[32] Mutsuko Murakami, "Japan Stresses R&D in High-Performance Robots," *American Metal Market*, July 11, 1983, p. 9A.

[33] Eiji Nakano, "Potentialities of Japanese Robot Industry," *Journal of Japanese Trade and Industry*, published by Japan Economic Foundation, January 1982, p. 7.

[34] P. Aron, Daiwa Securities America, "Robots Revisited: One Year Later," Report No. 25, July 28, 1981.

market in software as well. Japan is apparently attempting to catch up in software by pooling R&D efforts. In 1982, for example, 25 Japanese corporations entered into a joint agreement with the University of Tokyo to develop software for mechanical design.[35]

- Systems of computerized devices (including programmable automation) are in general more sophisticated in the United States than in other countries.

However, there are several areas in which other countries are leaders:

- The field of manufacturing engineering has undergone a slump in the United States in the past decade, according to many observers, with the best engineers avoiding work that was considered less intellectually exciting and "dirtier" than more theoretical efforts. Although this slump has occurred in other countries as well, West Germany's industries and technical universities have maintained a very strong program of production research and manufacturing engineering. Research, although partly funded by the government, is conducted autonomously through industry/university consortia. West Germany and Sweden have been very strong in precision machine tools and robots, in part because of the understanding of mechanical processes obtained from these institutes.
- Two foreign research efforts, one a joint Norwegian-West German program and the other under Hitachi in Japan, are pursuing ambitious work in developing more fully integrated CIM, starting with the geometric modeling of the product. Both projects aim to produce preliminary products in the next 2 years. At this time it is unclear how these projects compare with similar integration work, particularly at GE, IPAD and ICAM, and NBS.
- European countries in general are stronger in research relating to the effect of automation technologies on the work environment. This work is particularly emphasized in Sweden, where the Swedish Work Environment Fund administers research funded by the government and industry. Chapter 5 covers these efforts in more detail.

There is significant interest in programmable automation in Eastern Bloc countries, although there is limited information on their efforts. One U.S. robotics researcher, after a tour of the U.S.S.R., wrote:[36]

> Overall, I must conclude that the robotics technology in Russia is at least a decade behind that in the United States. They have apparently recognized this fact and now have a national program in this emerging technology.

Another writer described very substantial development efforts, particularly for FMS, in East Germany, Czechoslovakia and the U.S.S.R.[37] East Germany has a well-developed machine-tool industry and an extensive program on robotics development. Bulgaria and Poland have factories which produce manipulators.[38] On the whole, evidence seems to indicate that the Eastern Bloc countries are a few years behind the West, though there are concerted efforts in these countries to correct this situation. Reliable data and descriptions of programs in Eastern Bloc countries are rarely available.

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[35] Industry and Trade Strategies, unpublished paper prepared for OTA, April 1983.

[36] D. Tesar, director, Center for Intelligent Machines and Robotics, University of Florida, personal communication, Aug. 3, 1981.

[37] "CAM: An International Comparison," *American Machinist*, November 1981, special report 740. (The section on Eastern Europe was written by Jozsef Hatvany of the Hungarian Academy of Sciences).

[38] B. Roth, Stanford University, personal communication, October 1983.

Chapter 9

International Support for Programmable Automation

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Chapter 9

International Support for Programmable Automation

Summary

Many of the industrialized nations support the development of programmable automation (PA) to some extent. The degree to which such support has been effective is not easy to determine. It is confounded by other factors, including technological sophistication, industry characteristics, and cultural differences. However, the efforts which seem to be most successful are those which conform to and build on existing social and economic traditions.

The **Japanese** Government, mainly through the activities of its Ministry of International Trade and Industry (MITI), has developed long-range plans for economic growth, productivity growth, and export competitiveness. The most notable contribution of MITI has been to encourage the diffusion of PA technologies to small and medium-sized firms. In this way MITI has also stimulated low-cost, mass production of the low-end products of the PA market. This has helped Japanese producers become strong competitors in the international PA market.

Since the mid-1970's, **West Germany** has been committed to enhancing the international competitiveness of the advanced technology sectors of its economy through strong support of research and development (R&D). The Ministry for Research and Technology (BMFT) is the lead agency for coordinating science and technology policy with overall macroeconomic policy goals. BMFT has established an Advanced Manufacturing Technologies Program in order to promote the riskier types of innovation in this sector. The government has placed a strong emphasis on developing an understanding of the ways in which PA will affect the workplace and the labor force.

In the 1980's, the **Swedish** Government began to devote more resources to long-term research in PA in the hopes of bolstering Swedish economic growth. The Swedes are already significant robot producers. The Government also has a strong interest in education and retraining, which is consistent with its traditionally strong manpower policies.

The **French** Government under Mitterrand has made a strong commitment to speeding up the development and diffusion of PA, in part to enhance competitiveness. Japan and Sweden have set up robot manufacturing facilities in France as part of a Government strategy for technology transfer. The French Government has also shown concern for the human impacts of the implementation of PA.

The Department of Industry and Trade in the **United Kingdom** has a set of "schemes" to promote capital investments in PA. To date, however, these schemes have not been notably successful in promoting the diffusion of PA in Great Britain. The Government recently set up a national advanced technology research program to support R&D in PA industries, among others.

Norway has no extensive Government programs to encourage PA, although its production and application are progressing. The Government is urging the development of new technologies to promote industrial expansion. It has also identified key social impacts that the transition to advanced technology industries is having on the labor force.

The **Canadian** Government is playing a large role in encouraging the development and implementation of PA. It has developed model programs for Government investment strategies and for encouraging labor-management cooperation in dealing with dislocation, retraining, and work environment issues. The programs are new and the development effort starts from a relatively modest base.

Italy is a significant producer and exporter of machine tools and industrial robots. Some predict that Italy may also become one of the top five producers of industrial robots by the 1990's.

Introduction

Technological change and evolving patterns of international trade have focused attention on government policies relative to PA and on their potential effects on the development of manufacturing sectors among nations. This chapter describes policies and programs abroad which are directed at the development and use of PA, focusing on countries most actively engaged in PA production and use.* While other chapters discuss international comparisons in specific areas, this chapter provides complementary descriptions of major foreign government programs.

In each country discussed here, PA technologies can be found in different phases of development and adoption. The rate of adoption depends on the nature of each country's manufacturing sector, the availability of appropriately skilled labor, the nature of public and private research efforts, and such factors as capital availability, awareness of the technologies and their capabilities, and government incentives to encourage implementation.

Industrialized nations have different traditions of government involvement in technology and industry development. The distinctive cultural, social, political, and economic characteristics of each nation shape its policies. The course of development among national manufacturing sectors also varies, depending on the size of the economy, the nature of the local capital market, the extent to which the economy depends on exports, and the flexibility of the labor market. These national differences make it difficult to measure and compare the effects that microeconomic and macroeconomic policies have on a country's competitive advantage in international trade, its industrial mix, and its employment profile. International differences also militate against the direct transplantation of foreign programs to other countries. Finally, the availability of information about foreign support for PA is very uneven, and the timeliness and accuracy of that information is a recurring problem for international comparisons regarding PA. Nevertheless, this discussion is offered for illustrative purposes and to provide a measure of the level of foreign government interest in PA.

Industrial and technological development abroad appear to reflect less the dollar **amount** of government support than the **nature** of government programs and their relation to existing political, economic, and social conditions. It is not clear that current PA R&D programs in the United Kingdom and France, for example, have been notably successful. The climate for research and the mechanisms for assuring that research results are disseminated to industry in those countries may not be as favorable as in the United States. For example, the mobility of researchers between industry and universities appears to be greater in the United States. Moreover, Europeans are currently concerned that loss of their top scientists to the United States may diminish their prospects for economic growth.[1]

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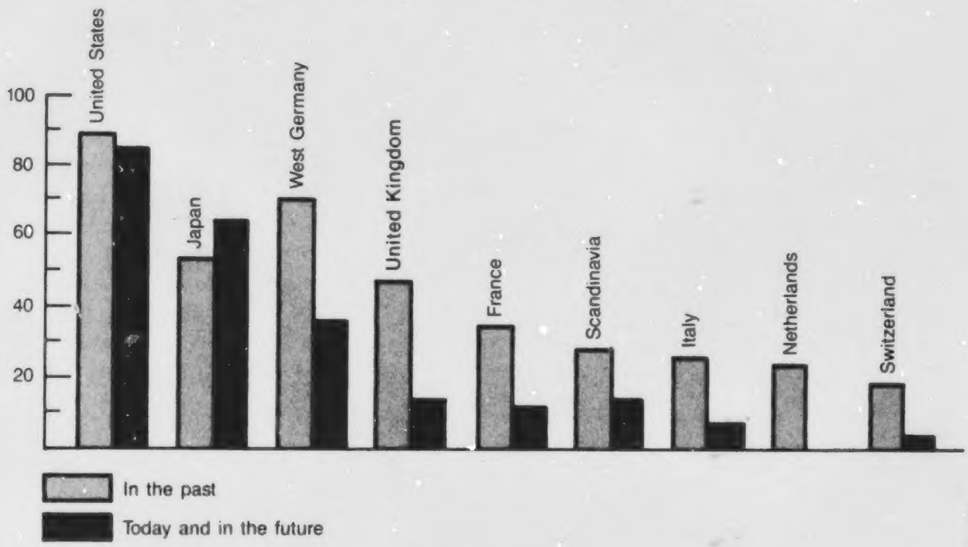
*Note that reliable and useful information on support for and use of PA in Eastern bloc countries is virtually nonexistent. Hence, these countries are not included in this analysis. In addition, other countries not covered here, including many in the Third World, also produce and use PA to a limited extent. For example, the use of CAD systems for mapping applications is growing in less developed countries.

A group of more than 200 European corporate chief executives recently surveyed by the *Wall Street Journal* "believe their continent has declined as a source of technology leadership, with the U.S. maintaining its top position and Japan gaining in importance."[2] Figure 39 shows how the executives rated different nations in technological leadership. The perceived losses in technological leadership by European countries—particularly West Germany and the United Kingdom—are striking. The explanations offered by the executives surveyed include a lack of trained personnel for developing and introducing new technology; relatively low status for technology issues and technical personnel within corporations; and a strong conservatism among European businessmen. These factors result in part in an emphasis on technology for cost reduction, as opposed to innovation as a source of new products, improved product performance, or improved customer service. It is interesting to note that most of the problems cited by European executives have also been cited in similar studies in the United States.[3] According to the *Journal* survey, European executives apparently believe that U.S. corporations are responding to those problems more effectively than they are themselves, despite domestic criticism of U.S. industry and policies.

Figure 39.—European Executives Pick Technological Leaders[a] (percent)



[a] Respondents could choose more than one country

SOURCE: *The Wall Street Journal* and Booz-Allen & Hamilton, Inc., survey of more than 200 chief executives of corporations in 16 foreign countries as reported in *The Wall Street Journal*, Feb. 1, 1984, p. 28.

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[1] Diane L. Coutu, "European Nations Fret Over Mounting Losses of Scientists to the U.S.," *The Wall Street Journal*, Oct. 21, 1983.

[2] J. Huey, "Executives Assess Europe's Technology Decline," *The Wall Street Journal*, Feb. 1, 1984, p. 28. The *Journal*, Booz-Allen & Hamilton, Inc., and HR&H Marketing Research International of London selected the executives from the top 1,000 companies in Europe ranked by revenue. The *Journal's* coverage is based on responses to the survey, Booz-Allen's analysis, and the work of the *Journal's* reporting staff. The *Journal* writes: "The survey isn't intended to be statistically rigorous, but it represents probably the most comprehensive current survey of executive attitudes regarding the technology on a pan-European and multi-industry scale."

[3] See, for example, R. H. Hayes and W. J. Abernathy, "Managing Our Way To Economic Decline," *Harvard Business Review*, July-August 1980, pp. 67-77; R. G. Shaeffer and A. R. Janger, The Conference Board, "Who is Top Management?" report No. 821, 1982, as well as other Conference Board reports.

On the other hand, European countries tend to focus more attention, political support, and research on the human aspects of automation than does the United States. Attention to social issues related to PA parallels traditions in many countries of strong programs for employment security and training and prominent representation of labor groups in the political arena. Concern abroad for the employment effects of PA is high and likely to grow in light of the relatively low rates of job creation in many European countries and the labor displacement potential commonly associated with PA. Recent analyses by the Organization for Economic Cooperation and Development, for example, concluded that the United States had created 22.5 million new jobs since 1980, while industrial employment in Western Europe fell by 1.5 million in the same period.[4]

The following sections describe policies and programs in each country related to both the social and technical aspects of PA.

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[4] Paul Lewis, "Nations Seek Key to Growth," *The New York Times*, Feb. 15, 1984.

Japan

Direct Government Role

Given Japan's scarcity of indigenous natural resources and its reliance on other nations for imports of food, energy, and raw materials, the Japanese strive to maintain a high volume of exports. Thus, international competitiveness and the ability to sell abroad is of crucial importance to the Japanese economy. Over the last decade Japanese firms have made a concerted effort to increase export sales in manufacturing industries.[5] Figure 40 demonstrates how the character of Japanese exports and imports has changed dramatically in the past few decades, partly as a result of the stewardship of MITI.

Since the Meiji Restoration in 1868, there has been a tradition of Government-industry cooperation, and the Government has historically been able to intervene effectively in the economy. Thus, industry has traditionally tended to view Government as a partner, rather than as an adversary or regulator. In recent years, however, this cooperative relationship has appeared to break down to some extent, as evidenced by the ebbing role of the Ministry of International Trade and Industry (MITI).

MITI was organized in the late 1940's from the Commerce and Industry Ministry, and its name reflected a new emphasis on international trade. While the agency has less independent power than is commonly ascribed in the United States, MITI works closely with industry associations and other Government agencies. For example, a standard practice is for a former official from the MITI staff to join the staff of an industry association and act as a liaison. The agency sets broad industrial policy, collects information on relevant research in other countries, and promotes special studies where information is lacking. The observation that MITI's role may be decreasing seems to be based on two major trends: First, the agency played a major role in allocating scarce capital in the postwar period, while capital shortages are now much less severe. Second, many Japanese industries (automobiles, for example) have become very strong; hence, they require less aid and resist MITI's involvement.

The Japanese Government has encouraged the movement of people and resources into sectors with a potential for high growth and high productivity. Japan's long-term economic plans call for reducing the importance of the country's agricultural and manufacturing sectors, and expanding the economic role of the

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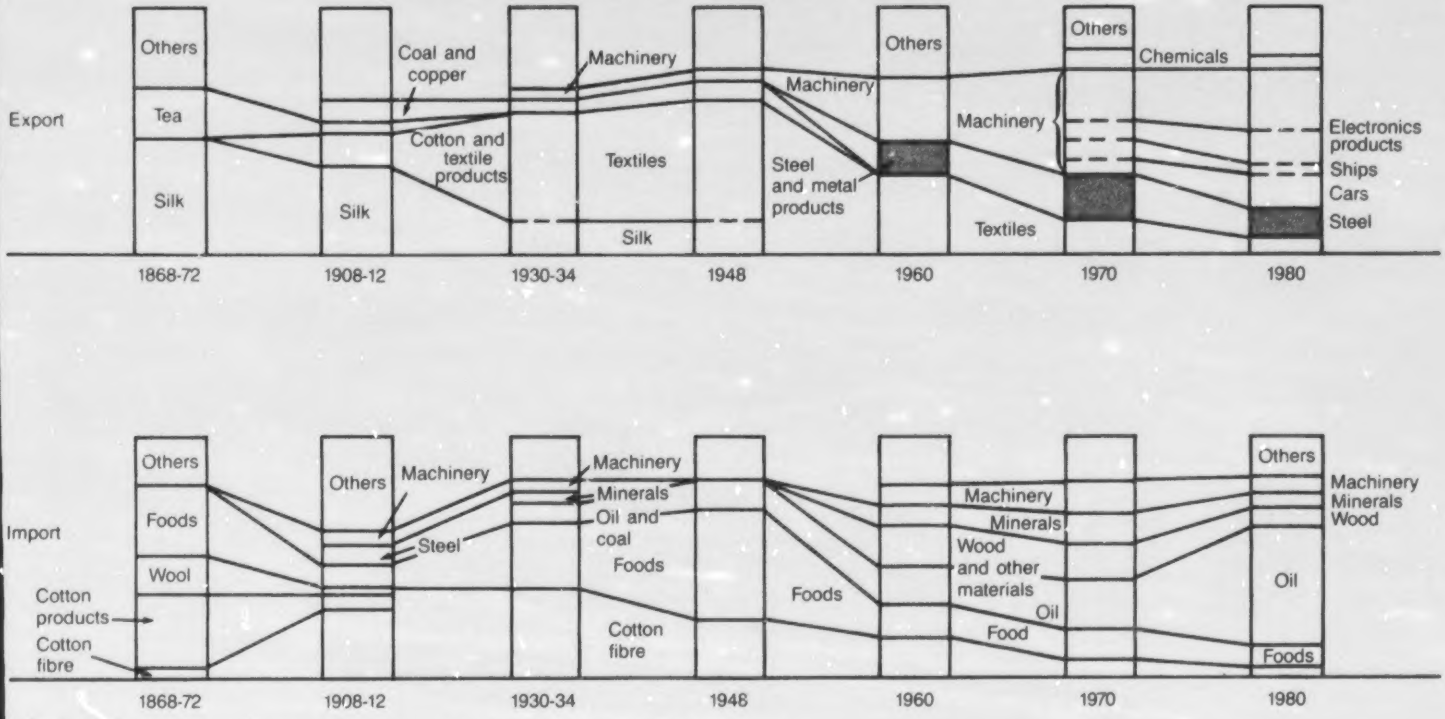
[5] Japanese Ministry of International Trade and Industry, "White Paper on International Trade," September 1982, p. 50.

Figure 40.—Long-Range Trends in Japanese Exports and Imports



SOURCE: I. Yamauchi, "Long-Range Strategic Planning in Japanese R and D," *Futures*, October 1983, p. 337.

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less energy-consuming, knowledge-intensive service sectors. MITI sees this as following a long-term trend which is already evident in the United States. It encourages this shift by promoting productivity and quality control gains and reductions in labor, energy, and materials costs. PA is one means toward these ends.

Government Mechanisms

Industries currently targeted for development by the Government in Japan include computers, microelectronics and electronics, lasers, fiber optics, biotechnology, robotics, aerospace, and telecommunications.[6] The instruments of industrial development policy include:

- *Visions.*—These are Government-sponsored papers elaborating on current economic challenges facing Japan, and discussing strategies to meet these challenges. MITI writes these documents in collaboration with industry, labor, and political interest groups.[7] The visions are intended to aid business and Government agencies in strategic planning.
- *Government Assistance.*—The Japanese Government provides small amounts of financial support for R&D in private firms in order to serve as "a catalyst to stimulate private sector support of mutually agreed upon industrial development policy goals."[8] In general, the role of Japanese universities in research is much less significant than the role of industry, and much less prominent than that of their counterparts in the United States.
- *Rationalization Cartels.*—In the late 1960's, in order to promote the development of internationally competitive firms in Japan, MITI guided the restructuring of Japanese industry by encouraging corporate mergers. (An increase in the number of new enterprises in Japan throughout the 1960's had resulted in strong domestic competition and a destabilization of Japanese industrial activity.) There continues to be a high level of merger activity toward the ends of enhancing management, maximizing the use of R&D, and facilitating the movement of capital among activities. Mergers are also motivated by the costs for large-scale investments in R&D and equipment.[9] It has recently been observed that companies are beginning to resist MITI-encouraged mergers as domestic competition in high-technology industries increases.
- *Tax Incentives.*—Special depreciation allowances exist for designated plant and equipment, in order to encourage development of targeted industries.
- *Monetary Policies.*—Throughout the postwar period, up until the early 1970's, the Japanese rationed credit. The Bank of Japan controlled the discount rate to influence microeconomic decisions. "Typically, this ability was used to bias flows toward investment in productive infrastructure and capital-intensive manufacturing and away from consumer spending, housing and social infrastructure."[10] This control eroded in the 1970's as Japan joined the International Monetary Fund (IMF) and the Organization for Economic Cooperation and Development (OECD), and its capital market became more internationalized for a number of reasons.

Government Concern for Social Impacts of Technological Change

The Japanese Government has strong concerns about the social impacts of increased application of PA and other new technologies in the manufacturing sector. The Japanese Ministry of Labor released a report in May 1983 entitled, "Microelectronics and Its Impact on Labor." The report focuses on the employment effects of robots and microelectronic products and processes in Japanese firms. In response to the employment effects of changes in production technologies in Japanese industry, the Ministry of Labor has requested funds for the establishment of a "policy department" within the ministry. This department would monitor employment trends and allow the ministry to develop recommendations which would be considered in the development of national economic policy.[11]

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[6] Harold B. Malmgren and Jack Baranson, *Technology and Trade Policy: Issues and An Agenda for Action*, Washington, D.C.: October 1981; and Cabinet Council on Commerce and Trade, *An Assessment of U.S. Competitiveness in High Technology Industries*, U.S. Department of Commerce, ITA, February 1983.

[7] Jimmy Wheeler, Merit Janow, and Thomas Pepper, *Japanese Industrial Development Policies in the 1980's: Implications for U.S. Trade and Investment* (New York: Hudson Institute for the U.S. Department of State, October 1982).

[8] Ibid.

[9] MIT Center for Policy Alternatives, *National Support for Science and Technology: An Examination of Foreign Exchange*, 1976.

[10] Wheeler, et al., op. cit., p. 7.

Government Support to Industry

The Machine Tool Industry

A fundamental difference in the approach of the United States and Japan toward support of the machine tool industry is that U.S. programs have developed machine-tool technology for military production purposes, while the Japanese Government encouraged broad industrial application of new machine-tool technology.[12] The Japanese approach included government-funded research institutes, which allowed Japanese firms to spend less on R&D than private U.S. firms generally considered necessary. Japanese research institutions were particularly responsive to the suggestions and experience of commercial end-users of the technology.[13]

Japanese competitiveness in the low end of the world machine-tool market reflects the widespread application of the technology in the domestic economy. The Japanese Government provided technical information and assistance to small and medium-sized firms to encourage the application of machine-tool technology in industrial production. Government-sponsored technical centers provided cost-benefit estimates, customized software, and training to firms interested in numerically controlled (NC) machines. By reducing user uncertainty and costs, the Japanese have been able to develop both domestic and international markets for small NC machine tools.[14]

The Robot Industry

The Japan Industrial Robot Association.—In 1971, the Industrial Robot Roundtable was established; this was a precursor to the Japan Industrial Robot Association (JIRA). Formed in 1972, JIRA was initially a Government corporation financed by the proceeds of sports events sponsored by the machinery industry. In 1973, JIRA became an incorporated private association. This configuration allows MITI to deal with robot producers as a group. One-third of Japanese robot producers belong to JIRA, as do many Japanese and foreign robot users.[15] JIRA's function is to promote the development of the robot industry through market surveys, the monitoring of technological advances, public relations, and development of new applications for robot systems. JIRA has been much more advanced in the collection and dissemination of information about robots and their uses than the association's counterpart in the United States, the Robotic Industries Association (RIA, formerly the Robot Institute of America). However, RIA is moving to bolster its information gathering and dissemination capabilities.

Japan Robot Leasing Co.—MITI has promoted the development and application of robot technology as one means of pursuing its overall strategies. However, the Japanese robot industry received little Government assistance until the late 1970's. In April 1980, MITI encouraged the establishment of the Japan Robot Leasing Co. (JAROL). JAROL was established in order to promote the use of industrial robots throughout the Japanese economy. The company leases robots primarily (90 percent) to small and medium-sized enterprises. JAROL is jointly owned by 24 major robot producers and 10 life insurance companies. The company initially received no Government funding, but now receives 60 percent of its financing from the Japan Development Bank in the form of low interest loans. The remaining 40 percent of JAROL financing comes from the Long-Term Credit Bank, the Industrial Bank of Japan, and various city banks. These favorable capital rates allow JAROL to lease robots at more favorable rates than ordinary leasing companies can offer. Nevertheless, other leasing companies and large robot vendors have also offered leases to robot users. JAROL received approval to extend leasing to companies abroad in the spring of 1983.[16]

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[11] U.S. Embassy, Tokyo, Japan, unpublished summary of Japanese Ministry of Labor Report on Microelectronics and Its Impact on Labor, Aug. 5, 1983.

[12] See National Machine Tool Builders' Association, petition to the U.S. Department of Commerce under the National Security Clause for adjustment of imports of machine tools, Mar. 10, 1983; and the response from the Japan Machine Tool Builders' Association, June 27, 1983.

[13] National Academy of Engineering, *The Competitive Status of the Machine Tool Industry* (Washington, D.C.: National Academy Press, 1983), p. 31.

[14] Industry and Trade Strategies, unpublished contractor report for OTA.

[15] U.S. General Accounting Office, *Industrial Policy: Case Studies in the Japanese Experience*, Oct. 20, 1982.

Financial Incentives.—MITI has also encouraged the development of several fiscal and financial incentives to promote robot installation. Low interest loans are provided to small and medium-sized enterprises through the Small/Medium Business Finance Corp. (Chusho Kigyo Kinyo Koko) and the National Finance Corp. In addition, interest-free loans of up to 12 million yen ($51,000*) are provided by the Government to small and medium-sized enterprises for the modernization of manufacturing facilities.[17] In order to promote robot applications for dangerous jobs, loans are available at 8 percent interest for the first 3 years and 8.3 percent for the remaining life of the loan. The Government budgeted 5.8 billion yen ($24.8 million) for these loans in 1980. In addition to ordinary depreciations, a special depreciation allowance was established in April 1980 for those firms installing industrial robots. A manufacturer who installs robots is permitted to depreciate 12.5 percent of the original purchase price in the first year, in addition to ordinary depreciation allowances. This may allow a firm to depreciate its robots as much as 52.5 percent during the first year. The depreciation rate was lowered to 10 percent for 1984 and 1985; the program is due to expire in 1985, though it may be renewed.[18]

Research and Development

In 1977, Japanese industry provided 65.7 percent of R&D funds in Japan, while the Government provided 16.1 percent and universities and other groups provided the remaining 18.2 percent. By contrast, in the United States, industry provided 43.8 percent, Government 51.1 percent, and universities 5.1 percent. In the Federal Republic of Germany, industry provided 55.6 percent, Government 41.5 percent, and 2.9 percent came from foreigners[19] (see fig. 41).

The Japanese Government, like the United States and European governments, is modestly subsidizing R&D projects on robotics (table 72). MITI's Agency of Industrial Science and Technology has two laboratories in which a considerable amount of research on robotics is carried out—the Electro-Technical Laboratory and the Mechanical Engineering Laboratory. MITI has also developed cooperative projects among competitive robot manufacturers, who contribute researchers to the joint efforts. Public research has focused on theoretical problems that also tend to be relevant to applications—speed control, improved positioning accuracy, simplification and modularization of robots, sensory perception, and pattern recognition ability. These joint research efforts have sought to avoid duplication of research efforts by the producer firms. In addition, MITI, in conjunction with JIRA, spon-

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[16] Paul Aron, *The Robot Scene in Japan: An Update*, Report #26, Daiwa Securities America, Inc., September 1983.

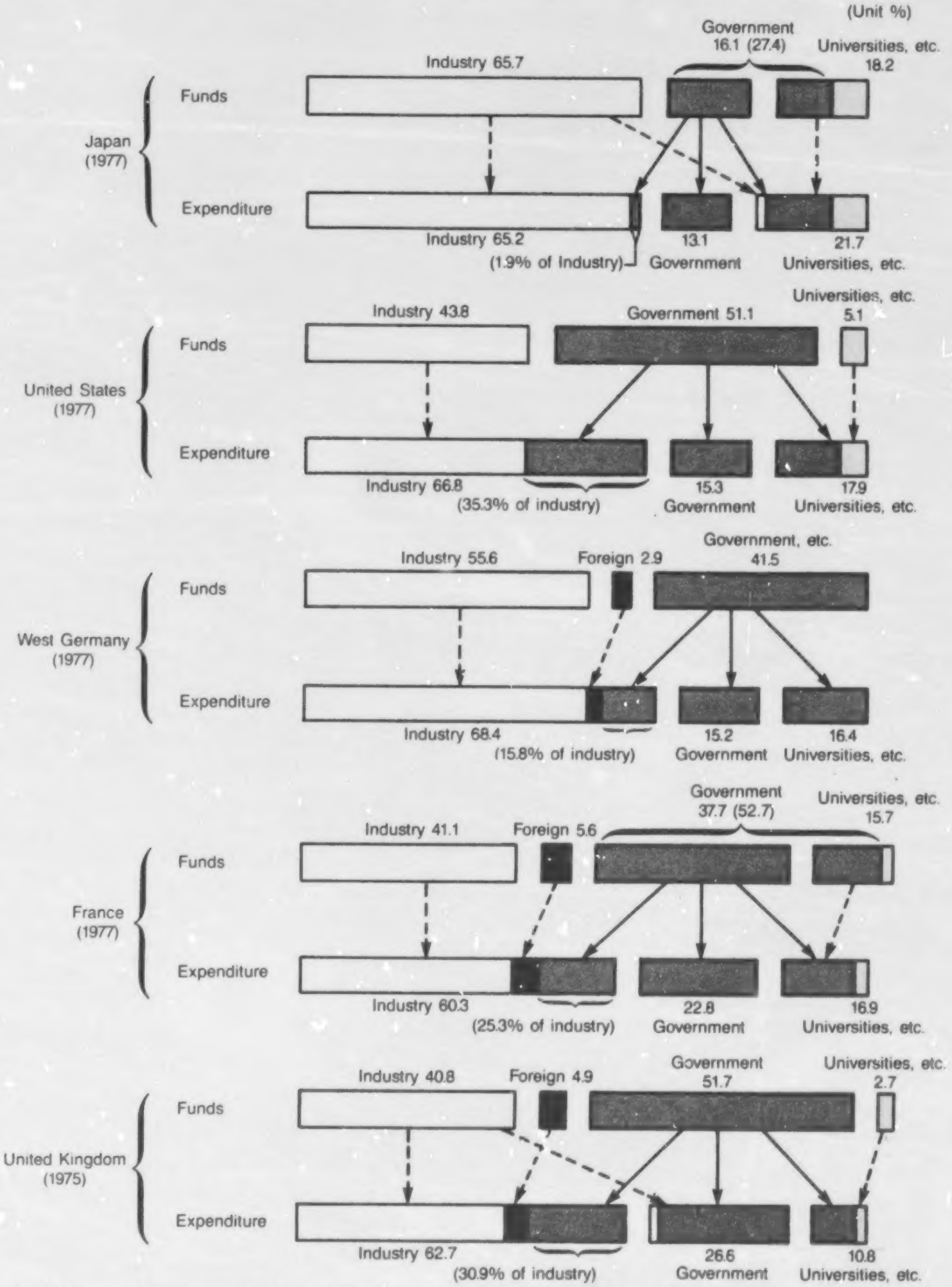
*Throughout this OTA report, foreign currency amounts are converted to their U.S. equivalent using foreign exchange rates in New York on Feb. 1, 1984, as cited in *The Wall Street Journal*, Feb. 2, 1984. Because the dollar was extraordinarily strong compared to foreign currencies at that time, the U.S. dollar equivalents given in this report are lower than they would be under more typical foreign exchange conditions. For reference, the exchange rates used are $1 = 234.25 Japanese Yen, 0.7089 British Pounds, 1.2473 Canadian Dollars, 8.5425 French Francs, 7.853 Norwegian Krone, 8.1425 Swedish Krona, and 2.7925 West German Marks.

[17] William Rapp, Commercial Counselor, U.S. Embassy, Tokyo, personal communication, October 1983.

[18] GAO Industrial Policy Case Studies, op. cit., pp. 25-27; and Paul Aron, Daiwa Securities America, Inc., "Robots Revisited: One Year Later," Report #25, July 28, 1981, p. 16 as reprinted in OTA Commissioned Background Papers to the *Exploratory Workshop on the Social Impacts of Robotics*, February 1982.

[19] "Science and Technology White Paper '81 Released," *Science and Technology in Japan*, January 1982, p. 9.

Figure 41.—Government/Industry/University Shares of R&D Funds and Expenditures



SOURCE: *Science and Technology in Japan*, January 1982, p. 9.

Table 73.—Government-Sponsored R&D Projects on Robotics in Japan

Project	Period	Sponsors
Industrial Robots Standardization Project	1974-81	AIST/MITI[a]
Research Assembly Work	1976-78	Japan Small Auto Promotion Association
Research Project on System Design in Computer-Assisted Robot System Engineering	1976	Japan Machine Industrial Association
Laser Based Flexible Manufacturing System Technology Research Project	1977-84	MITI
Development & Research Project of Multiple Production System Adapting Super-High Lasers	1978-83	AIST
Research Project on Robotizing Cast Finishing Work	1978-83	Small Business Corporation
Research Project on Automatic & External Assembly of High-Rise Buildings	1978	Japan Machine Association
Technology Assessment of Industrial Robots	1980	Japan Industrial Technology Promotion Association

[a] AIST—Agency of Industrial Science and Technology; MITI—Ministry of International Trade and Industry.

SOURCE: William Rapp, Commercial Counselor, U.S. Embassy, Tokyo, personal communication, Oct. 13, 1983.

sors the wide dissemination of resulting research data.[20]

Beginning in April 1982, MITI was to carry out a 7-year, 30 billion yen ($128 million) robot research program. It was intended to develop robots suitable for wider application, as well as to develop indigenous Japanese robot technology in order to reduce reliance on American and Western European innovations. The program was postponed for a time due to budgetary constraints, but work began in fiscal year 1983, and is still expected to be carried out over the envisioned 7-year period with full funding.[21]

Another of Japan's large-scale technology development schemes involves "developing complex production systems in which mechanical components for small-batch production of diversified products can be flexibly and rapidly produced from metallic materials in an integrated system."[22] Under this scheme MITI provided 20 percent [13 billion yen ($55.5 million) over fiscal years 1977-83] of the funding for the development of a Flexible Manufacturing Complex Utilizing Lasers.[23] The program did not finish on schedule, and was extended through 1984 with an extra 1 billion yen ($4.3 million).[24] The project had to be scaled down because extensive reliance on one large laser did not prove practical. The program has since incorporated more conventional applications. These applications, however, are not being used widely in the commercial sector for technical reasons. The project has become something of a "showcase" for advanced Japanese technology. Other projects aiming at computerized manufacturing integration are also underway in Japan, building on machine tool, robot, and computer research efforts.

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[20] Paul Aron, Report #25. op. cit., p. 17; and Paul Aron, Report #26, op. cit., pp. 26-27.

[21] Paul Aron, Report #26, op. cit.

[22] GAO Industrial Policy Case Studies, op. cit., p. 9.

[23] U.S. Department of Commerce, International Trade Administration, *High Technology Industries: Profiles and Outlooks, The Robotics Industry*, April 1983, p. 25.

[24] Federal Broadcast Information Service and GAO Industrial Policy Case Studies, op. cit., p. 28.

West Germany

Direct Government Role

Government expenditures as a percentage of gross national product in West Germany are relatively high compared to other European nations. The country has a highly developed social welfare system providing generous health, unemployment, and social security benefits; the system also permits a degree of worker participation in business management.[25] However, West Germany has no sharply defined industrial policy. It is similar to the United States in that Government support for industry is more or less decentralized, and there is substantial support at the State level. The Lander (States) can give housing grants to workers, grant land, and provide credit guarantees to attract new industries or preserve old ones.[26]

Since the oil crises of the 1970's, Government intervention in the German economy has increased in the form of direct subsidies, tax relief, special depreciation allowances, and preferential interest rates. The Government guarantees risk-capital loans to private business through Risk Financing Associations, which are made up of private banks. The Deutsche Wagnis Finanzierungs Gesellschaft (DWFG), formed in 1975, is a financing consortium owned by 28 large commercial banks and backed by the Federal Government to provide venture capital in the FRG.[27] The Government has also developed fiscal policy incentives to promote innovation, as well as an information network on new patents to ensure that they are effectively applied.

The Government provides over 90 percent of total R&D spending in Germany, although it provides only limited direction for research. The Ministry of Research and Technology (Bundesministerium fur Forschung und Technologie, or BMFT) is the coordinating agency for technology policy and the major provider of R&D funds. BMFT is concerned with general macroeconomic policy, promotion of innovation, and the health of small and medium-sized businesses. The Science Council, or Wissenschaftstrat, determines the objectives and priorities of R&D policy and makes budget allocations and recommendations. The Council is comprised of a board of experts from the Government [both the Bund (Federal) and Lander (State)], academia, industry, and the German research institutes. Although the recommendations of the Council are not binding, they carry considerable influence. The Wissenschaftstrat embodies the emphasis that German society places on scientific endeavors.[28]

Government Concern for the Social Impacts of Technological Change

Government-labor-industry relations in regard to encouraging and adapting to technological change are particularly good in West Germany. A well-developed communication network has been created between industry and Government through "quasi-public, semi-autonomous" research institutes and a system of advisory councils.[29] The foundation for concerted action between labor unions and employers' associations on the one hand, and Federal, State, and local government officials on the other, was established in 1966 with the Stability and Growth Act. Regular consultation between Government ministers and labor union officials on matters concerning industrial policy, income policy, and international competition and trade policy has evoked a social consensus.[30] The potential social impacts of technological change (particularly those that may take place within the workplace) have been part of the political agenda. Throughout the 1970's, following the German Social Democratic Party's rise to power, a large number of occupational safety and health measures were enacted by the Federal Republic of Germany. See chapter 5 for a more detailed discussion of relevant legislation and the Humanization of Work Program, which is a central feature of Government action to address the social impacts of technological change.

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[25] MIT Center for Policy Alternatives, *National Support for Science and Technology: An Examination of Foreign Exchange*, 1976.

[26] Wolfgang Hager, *National Industrial Strategies and the World Economy*, William Diebold and John Pinder (eds.), Atlantic Institute for International Affairs, Research Series, vol. 6, 1982, p. 241.

[27] "Venture Capital Struggles to Get Off the Ground," *Financial Times of London*, Feb. 11, 1983, p. 1c.

[28] Malmgren, op. cit.; and Massachusetts Institute of Technology, op. cit., pp. 14-23.

[29] Malmgren, op. cit., p. 39.

[30] *International Trade, Industrial Policies, and the Future of American Industry*, The Labor Industry Coalition for International Trade, April 1983, p. 30.

Government Support to Industry

Government Commitment to Small and Medium-Sized Firms

In the late 1970's, the Federal Republic of Germany initiated a number of programs to promote research, development, and innovation in small and medium-sized enterprises. The directing of technology policy toward these companies represents a growing awareness in the West German Government of the importance of such firms for innovation, growth, and employment.[31] These programs include funding for scientific and technical personnel, external contract research, and innovation consultancy.

Direct support of small and medium-sized enterprises by the BMFT has been rising. This reflects expansion of BMFT programs to include electronics, computer applications, and humanization of the working environment. In addition, the BMFT has increased its efforts to make smaller firms more aware of the Government support available to them. The Ministry for Economic Affairs (Bundesministerium fur Wirtschaft, or BMWi) assists small and medium-sized firms indirectly by supporting the Federation of Industrial Cooperative Research Associations (Arbeitsgemeinschaft Industrieller Forschungsvereinigungen, or AIF). AIF consists of more than 80 individual research associations which aid the smaller firms through publicity, research seminars, and technical advisory services. Another program administered by BMWi provides subsidies for 30 percent of the total cost [up to DM120,000 ($43,000)] of contract research placed by a small or medium-sized firm with a public or private research institution. The program is funded, however, by BMFT.[32]

The largest current program designed to support small and medium-sized firms is the "Program of Grants Towards the Costs of R&D Personnel." The program is administered by AIF on behalf of BMWi. It offers grants of 25 percent of gross wages and salaries, and 40 percent of the expenses of R&D personnel.[33] This program provided DM1.1 billion ($394 million) to West German industry between 1981 and 1983. Its objective is to nurture industrial innovation by providing subsidies for scientific and technical personnel. BMFT also provides free innovation counseling to small and medium-sized firms in several offices throughout the country. In addition, there is a Technology Center in Berlin which is linked to the German Engineers Association (VDI) to promote the diffusion of technology. This center provides information on the adoption of microelectronics and other technologies, assists firms in applying for R&D support from Federal agencies, and carries out studies on new technologies.[34]

Research and Development

The Ministry of Research and Technology (BMFT).—The Ministry supports approximately 6,000 projects in the form of grants to research societies such as the Max Planck or Fraunhofer institutes, national laboratories, and individual research groups in universities and industry. The 1983 budget breakdown is shown in table 73. It is expected that R&D funding will increase for biotechnology, information science, microelectronics, robotics, environmental protection, climatology, and public health.[35]

In 1980, BMFT established a program, called "Fertigungstechnik," which supports the development of advanced manufacturing technologies. The program is directed at R&D efforts in small and medium-sized firms in order to provide a high level of technological capacity in West Germany. In particular, it provides Government funds for risky R&D projects with high innovative potential.[36] The

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[31] "Impacts of Government Incentives Towards Industrial Innovation," Meyer-Krahmer, Gielow and Kuntze, *Research Policy*, June 1983, pp. 153-154.

[32] OECD, *Innovation in Small and Medium Enterprises*, Paris, 1970, p. 133.

[33] Labor Industry Coalition, op. cit.; and Dietmar Frenzel, Counselor, Science and Technology, Embassy of the Federal Republic of Germany, personal communication, Feb. 23, 1984.

[34] OECD, op. cit.

[35] U.S. Cable Traffic, American Embassy, Bonn, June 27, 1983, Robert Morris, Counselor for Scientific & Technological Affairs.

[36] Ibid.

Table 74.—Budget of the BMFT[a]

Category of expenditure	Millions of dollars
General (societies and institutes)	$ 217
Science and technology research	578
Information technologies	243
Energy	1,052
Space, oceanography, transport	514
Total	$2,604

[a]In U.S. dollars converted at $1 = DM 2.7915.

SOURCE: Robert Morris, Counselor for Scientific and Technological Affairs, U.S. Embassy, Bonn, FRG.

program distributes funds in the form of grants or loans for private, basic R&D, and private or commercial R&D that includes work on the commercial application of existing technologies. There is also Government-funded R&D activity in Government facilities and State-owned firms aimed at developing new technologies. The program spent DM44.1 million ($15.79 million) in 1980, and DM58.5 million ($20.95 million) in 1981, and planned significant increases for subsequent years. Due to budget cuts, however, only DM45.7 million ($16.37 million) were available in 1982, and only DM38.5 million ($13.79 million) in 1983.[37]

The Government is also involved in monitoring foreign technological developments, fostering Government-industry cooperation, establishing national standards, providing international educational exchange programs, and export promotion.

West German—Norwegian Collaboration

The Fraunhofer Institute for Production Systems and Design Technology (IPK) and three other West German industrial research institutes have been involved in a joint Government-sponsored research effort with the Norwegians for the last 2 years. The effort arose out of negotiations securing West German rights to drill for Norwegian oil, and it involves technical universities and industrial firms in both countries. The Norwegians and West Germans are developing an advanced production system (APS) for CAD applications in mechanical engineering. APS would integrate into a modular system existing programs for geometric modeling, NC machine tool programing, and process planning. The long-term goal is to develop a state of the art, computer-integrated manufacturing system to be marketed by the firms involved. The program is built around an advanced geometrical modeling system, which is designed to interface with all elements of a manufacturing system from design to assembly. APS is similar to the IPAD and ICAM projects being funded by the National Aeronautics and Space Administration and the U.S. Department of Defense (see ch. 8). The APS program, initiated in 1981, had an initial joint funding commitment of $45 million.[38]

R&D Tax Credit

The West Germans have instituted a special tax credit to promote R&D. A 40 percent depreciation allowance is granted for movable equipment utilized exclusively for R&D. A 15 percent depreciation allowance is available for fixed plant equipment which is utilized two-thirds of the time for R&D. Another 10 percent depreciation allowance is available for the construction cost of buildings of which at least one-third is devoted to R&D.[39]

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[37] Robert Morris, U.S. Embassy, Bonn, FRG, personal communication, Aug. 4, 1983.

[38] Eugene Merchant, Metcut Associates, personal communication; and *American Metal Market/Metal Working News,* "CAD/CAM Systems in Europe," Apr. 11, 1983.

[39] R. G. Morris, Counselor for Scientific and Technological Affairs, American Embassy, Bonn, personal communication, Aug. 4, 1983.

Sweden

Direct Government Role

The Swedish Government has traditionally played a very strong role in the Swedish economy. The Government owns 5 percent of Swedish industry, primarily in mining, public utilities, transportation, and communications.[40] Exports and imports accounted for an average 30 percent share of GNP between 1975 and 1980 in Sweden. Principal producers for export include shipbuilding, mining, steel, and forest industries. Nearly half of all Swedish industrial products are sold abroad, while almost all of the Swedish energy supply is imported. Machinery and mechanical equipment also make up a large share of Swedish imports. Given Sweden's dependence on external trade, international competitiveness is vital to its economy.

In the 1970's, Sweden was faced with serious structural economic problems. With what was traditionally an export-led economy, the country began to encounter increased competition in its major export markets. The oil price increases and high wage costs, combined with shrinking world demand and growing international competition, caused Sweden's major export sectors to deteriorate. The rise in value of the Swedish Crown as a result of the European Currency Agreement also hurt Swedish exports. The most immediate aim of economic policy in Sweden today is to lower relative prices of Swedish industrial goods on the world market, to regain Swedish market shares in both the export and domestic markets.[41]

The Swedish Government recognizes that production of PA equipment may be strategically desirable, and it is concerned about a possible shortage of skilled labor. Historically, Swedish Government outlays in support of active manpower policies have been relatively high. The Swedish "Active Labor Market" policy includes early and mandatory notification of plant closings, a virtual State monopoly on employment services, and extensive career counseling and support for training programs.[42]

Sweden's unique political and cultural context favors certain types of innovative programs, while it makes comparisons of Government policy with other countries particularly difficult.

Government Support to Industry

According to an official of the Royal Swedish Academy of Engineering Sciences:

> The ability of Sweden to compete on the world market for manufactured products will increasingly depend on the ability and willingness of Swedish industrial firms to invest in and use the new generation of manufacturing technologies.[43]

The National Industrial Board has also stressed the need to promote structural economic change in Sweden in response to changes in world markets and Sweden's deteriorating competitiveness. It has recommended three major types of policy measures. The first promotes development of production resources through investments in technology development and acquisition of capital stock in sectors that are expected to be competitive in the long term. The second emphasizes selection or targeting of those areas which are expected to produce the highest yields in the future. Finally, the Board stresses that the distribution of labor and capital in the production system may be strongly influenced by political concerns.

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[40] The Swedish Institute, "Fact Sheets on Sweden," September 1980.

[41] *Swedish Industry Up to 1990: Analysis and Policy Proposals*, National Industrial Board of Sweden, 1981 Autumn Report, pp. 84-85.

[42] M. Bendick, Jr., "The Swedish 'Active Labor Market' Approach to Reemploying Workers Dislocated by Economic Change," The Urban Institute, Washington, D.C., March 1983.

[43] Hans Anderson, Project Manager, Royal Swedish Academy of Engineering Sciences, personal communication, May 19, 1983.

The Swedish Committee on Labor Market Education and Training Within Industry

With respect to labor development, the Swedish Committee on Labor Market Education and Training Within Industry (KAFU) is currently studying Swedish needs for skilled labor. It is exploring whether or not the education and training system is supporting those with "a weak position in the labor market," and whether or not the Government should take action which would put personnel training directly within companies. Despite the active manpower policies, unemployment is still high, and there is some concern that Government-funded training programs are becoming just a "holding pen" for otherwise unemployed workers.[44] The National Industrial Board is also concerned about the supply of skilled labor and relevant Government responses.

The Swedish Commission on Computers and Electronics

In April 1981, the Swedish Commission on Computers and Electronics (Data-och Elektronikkomitten, or DEK) reported to the Minister of Industry on the promotion of PA in Sweden. According to DEK, large opportunities for improving productivity lie in:

> . . . optimally interconnecting various processes into computer-integrated manufacturing systems. In the engineering industries, and especially those subjected to strong international competition (automotive industry, computers and telecommunications, consumer electronics, household appliances, etc.), systems integration is regarded as the key to survival in the 1980's.[45]

CAD.—The Swedish Government has placed a high priority on promoting the development of CAD. In 1982, DEK introduced new legislation which included the allocation of 14 million Skr ($1.7 million) during 1982/83 in part for the formation of three CAD centers.[46] A DEK report lists the following motives for promoting the diffusion of these technologies throughout the economy: 1) to increase productivity and, thereby, profitability; 2) to improve the conditions of work; 3) to improve precision and tooling complexity; 4) to acquire experience with new technologies; and 5) to reduce consumption of energy and raw materials.[47]

DEK recommended that the Swedish Government coordinate activities promoting new production technologies, and, in particular, that it promote long-term technology development and skills development at technical facilities. It recommended enlarging the vocational training program at the Swedish Institute for Corporate Development (SIFU), and establishing a training program for vocational instructors on computer-based production technologies.[48]

The Program for Diffusion of Industrial Robots and Computer Controlled Production Techniques.—On April 1, 1983, DEK announced the Program for Diffusion of Industrial Robots and Computer Controlled Production Techniques. In order to promote wider use of PA in small and medium-sized firms that have little or no familiarity with PA, DEK proposed the following measures:

1. An information campaign revolving around the 14th Annual International Symposium on Industrial Robots (ISIR), which will be held in Stockholm in October 1984.
2. Support for production technology development projects.
3. Educational programs for project personnel.
4. Development of a consultancy program.
5. Regional educational programs which

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[44] Bendick, op. cit.

[45] *The Promotion of Robotics and CAD/CAM in Sweden*, report from the Computers and Electronics Commission, Ministry of Industry, LiberForlag, Stockholm, 1981, p. 1.

[46] Jan Carlsson, Computers and Electronics Commission, in a presentation at the IBM workshops: *Automation in Manufacturing: Effects on Productivity, Employment and Worklife;* Jafalla plant, Stockholm, Mar. 30-31, 1982, p. 24.

[47] Computers and Electronics Commission Report on the Promotion of CAD/CAM in Sweden, op. cit., p. 18.

[48] Ibid.

would include demonstration programs, including robot-assisted lathes and automated materials handling, robot welding and automated materials handling, and flexible automated machine loading.

To further international recognition of Swedish PA industries, ISIR will include visits to producer and user plants by foreign participants. DEK has also proposed a microelectronics campaign in Sweden. Finally, DEK has considered establishing direct support for the Swedish PA industry based on Japanese and British models. Because it found problems with establishing similar support mechanisms in Sweden, DEK did not take a firm position on this issue.[49]

The Swedish Board for Technical Development (STU)

The Swedish Board for Technical Development (STU) operates under the auspices of the Swedish Ministry of Industry, and provides funding for advanced R&D in universities, research laboratories, and industry. Between 1972 and 1979, STU funding for robotics and CAD amounted to approximately 25 million Skr ($3.07 million).[50]

Total STU support for R&D in engineering industries is expected to increase considerably, to 260 million Skr ($31.93 million) for the period 1980/81-1984/85.[51] Of this amount, 14 million Skr ($1.72 million) will go toward CAD and CAM R&D. Long-term projects are also planned for adaptive control of machine tools and industrial robots, and a 10 million Skr ($1.23 million), 4-year CAD joint venture project is planned between Saab-Scania, STU, and two universities.[52] Saab-Scania will eventually invest about 3 million Skr ($370,000) toward the commercial development of this CAD 80 system.[53] STU and the Swedish Association of Mechanical and Electrical Industries have agreed to sponsor a 5-year CAD and CAM research program. Their agreement calls for a commitment of 46 million Skr ($5.65 million) and 48 million Skr ($5.89 million), for STU and the association, respectively.[54]

France

The French Government has traditionally played a large role in the coordination, funding, and direction of the French economy since Jean Baptiste Colbert founded the Academy of Sciences in 1666. French Governments since have changed the scope and nature of that involvement but the traditional mechanisms used by Government have changed very little.

Since World War II, information technology, including PA, has been of major interest to the French Government and therefore to the French industrial and educational communities. Funding commitments, research, and industrial production for information technologies have been directed toward two major goals: 1) world recognition of France as a leading manufacturer of high technology products, and 2) the development of information technology-based systems and patterns of communication which could help preserve and develop French culture and society.

Recently, France's high technology push gained new strength. The last French Presidential election (1981) marked the first time science and technology was a political issue.[55] Indeed, all candidates had indicated that increased funding for R&D was one of their goals. Before losing to Mr. Mitterrand, Mr. d'Estaing had designed a plan for increasing real Government R&D funding 8 percent per year for 5 years beginning in 1980. When Mr. Mitterrand was elected, he more than doubled that goal. During 1982-85, the Mitterrand government had planned to increase R&D expenditures 17.8 percent with the objective of spending 2.5 percent of French gross national product on R&D by 1985.[56]

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[49] *Teknikspridningsprogram For Industrirobotar och Datorstodd Produktionsteknik,* IndustriDepartmentet, Data-och elektronikkommitten, DSI 1983:6.

[50] Computers and Electronics Commission Report on the Promotion of CAD/CAM in Sweden, op. cit., p. 30.

[51] Carlsson, op. cit., p. 25.

[52] Ibid., and Computers and Electronics Commission Report on the Promotion of CAD/CAM in Sweden, op. cit.

[53] Computers and Electronics Commission Report on the Promotion of CAD/CAM in Sweden, op. cit., pp. 30-31.

[54] Computers and Electronics Commission Report on the Promotion of CAD/CAM in Sweden, op. cit., p. 31, and Carlsson, op. cit., p. 25.

Mitterrand's emphasis on increasing R&D spending was part of an ambitious industrial policy for France which included employment and education policies as well as planned market programs in several areas of high technology, including PA.[57] The programs were all designed around the Socialist principles of decentralization, democratization, humanism, and volunteerism. For example, researchers are thought to have a social and economic function which capitalism has inhibited. More transfer of technology between industry and Government is seen as one way of enabling such functions to be undertaken and the nationalization of industries is considered to be the mechanism for achieving social and economic research.

Several key high-technology industries, including computers, telecommunications equipment, aircraft, and electronics have been nationalized. This is in addition to the previously nationalized automaker Renault, oil company Elf Aquitaine, and aircraft manufacturer Aerospatiale. Today, about three-fourths of all industrial R&D spending takes place in nationalized companies.[58] For information technology, including PA, the figure is considerably higher as almost every major industrial actor in the area has been reorganized to reflect a majority Government ownership interest.

Mitterrand has two high-technology plans for PA. (The plans both had roots in the d'Estaing government, but were reorganized by Mitterrand to reflect a stronger Government role and increased funding.) The first, published in April 1982,[59] includes plans for robotics, machine tools, and numerical control devices. It is often referred to as the Filiere Robotique.* The second technology plan for PA was published by the Ministry of Research and Industry in July 1982.[60] This is referred to as the Filiere Electronique and includes aid for CAD and CIM.

Filiere Robotique

Three goals have been announced for the Filiere Robotique: productivity improvements, better working conditions, and economic gain from the sale of PA equipment. The last goal is of particular interest to the French. Although Renault is France's largest manufacturer of PA equipment, representing 50 percent of France's industrial commitment to PA research, France still imports more than 50 percent of its PA consumption.[61]

The three goals of the Filiere Robotique are to be implemented through programs of increased R&D in robotics, automation, mechanics, electronics, hydraulics, and software; increased production of PA components and materials; diffusion of automation technologies; and the use of PA in a variety of economic sectors. In 1981, total French Government assistance to the Filiere Robotique amounted to 251 million francs ($29.4 million), of which 91 million francs ($10.7 million) went to R&D and 160 million ($18.7 million) to manufacturer assistance. Plans for 1982 included increasing the R&D budget by 29 percent and the aid to industry by 104 percent.[62]

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[55] Pierre Aigrain, "The French Experience in High Technology," Center for Strategic and International Studies, Georgetown University, Washington, D.C., p. 2.

[56] Interview with M. Morel, Conseiller Technique du President de la Republique, June 20, 1983.

[57] "French Technology Preparing for the 21st Century," *Scientific American*, November 1982.

[58] Ibid.

[59] *L'Utilisation de la Robotique Dans la Production et ses Perspectives D'Avenir*, Conseil Economique et Social, 2 Avril 1982.

*A "filiere" in France is a targeted industry grouping or other goal around which a Government plan for R&D funding, production investment, education, and dissemination assistance has been developed. There are six filieres in France today; robotics, electronics, energy, biotechnology, working conditions, and cooperation with developing countries.

[60] *Filiere Electronique, Plan du Dossier*, Ministre de la Recherche et de l'Industrie, 28 Juillet 1982.

[61] Ibid.

Within the Filiere Robotique there is a separate plan for machine tools. Le Plan Machine Outil is a 3-year venture in which the French Government expects to spend 2.3 billion francs ($269 million) from 1983-85. The plan's main objective is to double production of French machine tools within 3 years. Key elements of this effort, according to the French Government's published plan, were the nationalization of C.G.E., Saint-Gobain, and Thomson, and majority Government participation in Matra and Dassault. The French Government also expressed interest in reorganizing the commercial activities of small robotics material manufacturers,[63] but no course of action for such was detailed.

There are three Government ministries and nine separate agencies involved in the Filiere Robotique. The defense ministry, through its office of Space Research and Studies, has a project (Projet SOLARIS) to study the use of robots in space. The ministry of industry and research has 26 projects ranging from the use of robotics for the handicapped to their use in nuclear reactor inspection. Involved in these projects are the National Scientific Research Center (CNRS), the Institute for Computer Sciences and Automation Research (INRIA), the Data Processing Agency (ADI), the National Agency to Valorize (commercialize) Research (ANVAR), and the Atomic Energy Commission (CEA). The education ministry has a two-part research program which includes both the French university system and the Grandes Ecoles. In total, the French estimate that these projects involve the equivalent of between 250 and 300 researchers.[64]

The industrial component of this research activity includes collective centers (both trade associations and quasi-Government groups) formed around machine tools, textiles, petroleum, and other products. In addition, research is being carried out in both nationalized corporations such as Renault, and in private firms like Telemecanique.[65]

A related program is being carried out by the Agency for the Development of Automated Production (ADEPA) of the Ministry of Industry to promote the application of CNC machine tools, robots, flexible machining cells, and flexible manufacturing systems in small and medium-sized firms. Representatives from ADEPA identify possible users of PA equipment and invite the firms to participate in a 2-year trial use of PA in their production facility. Firms that agree are given equipment to use for 2 years and technical assistance from ADEPA. At the end of the 2-year trial period, the firm has the option of paying for the machinery (less 2 years' depreciation charges) or returning it and paying only the depreciation cost. Of the first 100 companies that participated, almost none returned the equipment.[66]

Filiere Electronique

This program's stated long-term goal was to place France on a technological level in electronics equal to that of the United States and Japan. The infusion of 140 billion francs ($16.4 billion) in R&D funds over the 5 years following 1982 was expected to produce a surplus balance of trade in information technology, create 80,000 new jobs, assure mastery of information technologies, and accelerate the production of information technology products by 3 to 9 percent each year. Eight areas of achievement were outlined:

- computer-aided circuit design for very large scale integrated circuits,
- computer-aided design and manufacturing,
- artificial intelligence,
- computer graphics,
- peripherals,

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[62] Ibid.

[63] Ibid.

[64] Ibid.

[65] Ibid.

[66] Eugene Merchant, personal communication; and *An Assessment of the Industrial Energy Conservation Program for the Pulp and Paper and General Manufacturing Industries*, National Research Council, National Academy Press, 1983, p. 14.

- computer-aided translation,
- computer-aided instruction, and
- consumer electronics.

In January 1983, the Ministry published its plan of action.[67] In the area of computer-aided design and manufacturing, an evaluative group was assembled to design research, development, and production plans. The group's members included the Direction Generale des Telecommunications (part of the national telephone concern), the Delegation Generale aux Armements (part of the Ministry of Defense), DEILI (Direction des Industries Electroniques et de l'Informatique; part of the Ministry of Industry and Research), ADI, CNRS, and INRIA.

This group, along with several others formed in the other areas of the Filiere, created Le Projet Cadre, designed to pursue four areas of inquiry: scientific calculation, CAD, management of information technology product production, and software development for PA.[68] The implementation plans for this project were not specified.

Implementation of the Filieres Electronique and Robotique

The public announcements concerning the electronics and robotics sectors programs made in the year or so following the implementation of the programs (early 1982) became at once more ambitious and less specific, and were accompanied by reduced funding. Funding in 1982 for the electronics sector amounted to about 6 billion francs and 1983 expenditures were expected to be approximately 8 billion francs—far short of the proposed 28 billion each year.[69]

Funding problems for the Mitterrand government have been pervasive, and the plans for a vast effort in PA have suffered significantly as a result. In discussions with several French Government agencies involved in PA in the summer of 1983, it was revealed that the average agency cutback for 1983-84 was about 20 percent from levels projected in 1981; this not only virtually eliminates the increases desired by the Mitterrand government over that spent by d'Estaing, but for several agencies requires operating levels that are lower than those of the last administration. This reduced spending was not accompanied by a consolidation or reduction in the number of PA projects. The entirety of the robotics and electronics sectors plans are intact. The result may be that PA projects are funded at inconsequential levels.

Several other problems were encountered by the Mitterrand government in its effort to mobilize the country's PA resources. Substantial difficulty was encountered with nationalization, apparently due to a large philosophical divergence between executives among the targets of nationalization and the former Minister of Research and Industry.

Even without the financial constraints on French PA activities, there would still be serious manpower problems. The number of people with Level I qualifications (approximately equal to an American Ph. D.) in information technology is expected to fall short of needs by 70,000 for the period 1981-90 in France. In the French context, this number is quite large; in 1979 it was estimated that 105,000 scientists and engineers were actively involved in all aspects of French science (energy, pharmaceuticals, mechanics, etc., as well as information technology).[70]

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[67] Ministre de la Recherche et de l'Industrie, *Programme Mobilisateur*, 20 Janvier 1983.

[68] Ibid., p. 6.

[69] See for example, *A. F. P. Sciences*, No. 341, Jan. 17, 1983, pp. 1-4.

[70] Jean-Pierre Letouzey, Scientific Mission, Embassy of France, *Statement for the American Association for the Advancement of Sciences*, Mar. 24, 1983.

United Kingdom

Direct Government Role

The British Government, as a rule, does not actively intervene in the national economy as much as the Japanese or French Governments. The Government provides funds for R&D in risky areas and in areas with commercial potential. The Department of Trade and Industry (DTI) has recently developed a set of schemes including support for R&D, feasibility studies, capital equipment investments, and demonstration programs, in order to encourage the implementation of PA in the United Kingdom.

Since World War II, the British Government has been spending sizable amounts in support of science and technology; however, the numerous British economic and technology policies have lacked a clear objective and have suffered from poor public-private sector cooperation. Overall, the British machine tool and robot industries are small, but the CAD and CAM software industry is strong. Financial support for "high-technology" industries has not been as great as support for the auto, shipbuilding, and steel industries. Since the latter half of the 1970's, DTI programs have focused more on commercial exploitation of new inventions than on R&D, per se, although mechanisms and funding have been provided to support research where private companies have been reluctant to invest. These programs have not always resulted in commercially successful products, the most notable example being the Concorde.[71]

In the late 1970's the Labour government investigated PA. The two most noteworthy efforts yielded the ACARD report (named after the Advisory Council for Applied Research and Development, which is responsible for advising Government ministers) and the Ingersoll report. The ACARD report documents a working group's effort "to consider the effectiveness of technology transfer and the adequacy of current research and development on joining and assembly in relation to the needs of U.K. industry, and to make recommendations."[72] It noted that the United Kingdom had many fewer robots in place than other industrialized countries, and it recommended accelerated application of PA.

DTI's predecessor, the Department of Industry, commissioned a report on industrial robots from Ingersoll Engineers in 1979. The report "outlined the scope for, and importance of, robotics, identified problems facing the take up of robots, and put forward a national robot programme, which foreshadowed the actual programmes followed by the Department of Industry and the Science and Engineering Research Council." Initially, under the Thatcher government, it appeared as though the initiative in PA would be left up to private industry. However, at the "Automan 1981" Conference, Prime Minister Thatcher, in a speech endorsing robotics, indicated the Government's willingness to take action to promote the use of PA in British industry.[73]

DTI also oversees an elaborate network of agencies encouraging R&D and the transfer of technology throughout the economy. These include the Research and Development Requirements Boards, Industrial Research Establishments, Industrial Research Associations, and the British Technology Group (BTG).

BTG was formed in 1981 as an independent public corporation set up to promote the development and application of new technology. It includes the former National Research Development Council (NRDC) and the National Enterprise Board (NEB). BTG attempts to ensure the commercial utilization of the results of Government-sponsored research and provides capital to private business in order to encourage innovations. While BTG is under the auspices of the Secretary of State for Trade and Industry, its day-to-day activities are free of Government intervention. BTG receives its operating income from royalties, licensing, and other forms of reimbursement. It also receives financing from DTI which it repays with interest.

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[71] Malmgren, op. cit., quoting Gilpin, p. 51; and David A. Brown, "Funding Dispute Snags British Program," *Aviation Week and Space Technology*, Apr. 18, 1983, p. 65.

[72] The report, entitled *Joining and Assembly: The Impact of Robots and Automation*, was released in October 1979. James Fleck, University of Aston, U.K., personal communication.

[73] James Fleck, personal communication.

In early 1983, in part as a response to Japanese and American efforts to develop "fifth generation" computers, the British set up a national advanced technology research program. A committee chartered by the Minister for Information Technology and headed by John Alvey recommended a Government/industry/university cooperative program aimed at four main areas: very large scale integrated electronic components, software engineering, man/machine interfaces, and intelligent knowledge-based systems.

The Government will pay half of the cost of this collaborative research effort in industry, and 100 percent of research costs in universities. The "Alvey Report" estimated that academic institutions should carry out £ 50 million ($70.5 million) of research over 5 years, and industry £ 300 million ($423 million), resulting in a Government expenditure of approximately £ 200 million ($282 million).[74]

Government Support to Industry

Research and Development

Support for Industry R&D.—A series of programs was set up in the late 1970's in order to promote the diffusion of technology throughout the economy; these included the Microelectronics Application Program (MAP), the Manufacturing Advisory Service (MAS), and a Robotics Advisory Service (RAS). MAS was established in October 1977 in order to increase the competitiveness of manufacturing firms by offering subsidized consulting services. Its budget in 1982 was £ 9.25 million ($13 million), with 80 percent going to small and medium-sized enterprises.[75] The RAS is operated by the Production Engineering Research Association (PERA), as is MAS. RAS offers an information service, a demonstration center, and subsidization of feasibility studies to assist small businesses in applying robots to production processes. DTI highlighted these programs as part of a campaign declaring 1983 "Quality Assurance Year." The intention is to make industry more aware of the Government financial support available to implement robots, flexible machining systems, CAD, and microelectronics. The year 1982 was declared "Information Technology Year," and relevant demonstration programs, public seminars, and conferences were held.[76]

The Science and Engineering Research Council.—The Science and Engineering research council (SERC) is one of five research councils funded by the Department of Education and Science. The function of the councils is to promote and sponsor basic research in universities and in Government. SERC's "Robotics Initiative" was announced in July 1980. It called for SERC to provide £ 2.5 million ($3.53 million) for the study of future generations of robots. The program has already resulted in the development at Oxford University of a laser scanning device for arc-welding applications.

Department of Trade and Industry Special Programs

The Robot Support Program.—DTI initiated the Robot Support Program in April 1981 in response to the recommendations of the ACARD and Ingersoll reports. The program was originally funded at £ 10 million ($14.11 million) in three areas: 1) Support for feasibility studies in order to allow a company to determine if robots would be cost-effective. A company may choose a consultant from DTI's list of approved consultants for the feasibility study. The Department will then pay 50 percent of the cost of the study for up to 15 person-days. 2) Support for robot purchase and installation. The Government will support up to one-third of the cost of the robot and associated capital equipment. Development costs such as the labor cost for development engineers, etc., and the cost of new tooling are covered by grants of up to one-third. The Department will also provide support for lease-financed robots. 3) Support for companies seeking to develop or manufacture robots. Grants are available for up to one-third of the costs of "projects involving the design and development by U.K. manufacturers of new industrial robots and associated equipment up to the point of commercial production."[77]

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[74] The Department of Trade and Industry, "A Programme for Advanced Information Technology," The Report of the Alvey Committee (London: Her Majesty's Stationery Office, 1982).

[75] OECD, *Innovation in Small and Medium Enterprises*, Paris, 1970.

[76] James Fleck, personal communication.

Despite these ambitious product and process development schemes, many companies applying for such funds have been turned down by banks with strict lending criteria, even though the Government guarantees 80 percent of the loans. Bank restraint has been attributed to the perception that many applicants show insufficient commitment to their projects. It is thought that as many as one in five of the participants may fail.[78] In addition, under the consultancy portion of the program, many firms decide not to implement PA because the new technologies do not appear to be the most cost effective manner of improving their production processes. Furthermore, the approved list of consultants provide by DTI includes a disclaimer as to the competence of the consultants.

By April 1983, the following funds had been committed under the Robot Support Program:

- 92 company installations . . £6.5 million ($9.17 million)
- 25 robot manufacturers . . £2.7 million ($3.81 million)
- 69 consultancies . £129,000 ($182,000)

DTI has been disappointed by the low level of interest from industry as measured by applications for funding. While the initial allocation of funds to the program may ultimately be spent, the future of the program is uncertain. However, robots will continue to be supported under a Flexible Manufacturing System Program (see below).[79]

Other Programs.—Similar programs have been set up under an umbrella "support for innovation" policy. These programs have been devised to promote CAD; computer-aided design, manufacture, and test of electronics devices (CADMAT); software development; fiber optics and opto-electronics; and flexible manufacturing:[80]

- *CAD.*—Government programs include demonstrations at firms, support for feasibility studies, management seminars, regional demonstration centers to permit "hands-on study," in-depth courses to aid design engineers and production managers in implementing the technology, grants of up to 25 percent for R&D involving new applications of CAD, and grants of up to 25 percent of cost "for the design, development or launch of new or significantly improved products or processes."
- *CADMAT.*—Government programs include management seminars, short courses for managers and engineers, demonstrations, a CADMAT information service on the state of the art of the technology and its applications, grants of up to 25 percent for the development of CADMAT tools and standards, grants of up to one-third of hardware/software costs, and support for installation and training costs of first-time users.
- *Flexible Manufacturing Systems (FMS).*—The FMS scheme was initiated in June 1982 with a budget of £60 million ($84.6 million). This scheme will provide selective financial assistance to cover some of the costs of feasibility studies, installation of a new FMS, and integrating existing plant into a flexible manufacturing system.

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[77] Department of Industry, U.K. brochure, "Government Support for Industrial Robots."

[78] Tim Dickson, "Caution Among the Bankers," *The Financial Times of London*, Sept. 18, 1983, p. 14.

[79] James Fleck, personal communication.

[80] Department of Trade and Industry Brochure, op. cit.

The "support for innovation" policy also is behind anticipated government funding for technical collaboration between Jaguar Cars, Ltd., British-owned Dainichi Sykes Robotics Ltd. (a joint venture between the British Sykes group and the Japanese Dainichi Kiko Company), and Dainichi Kiko. These companies recently agreed to develop new automated production systems for Jaguar automotive facilities.[81]

In addition, the National Engineering Laboratory and certain trade associations have received approximately £ 650,000 ($917,000) from DTI annually for robot-related studies. These grants have included £ 15,000 ($21,000) to support the establishment of the British Robot Association, and £ 240,000 ($339,000) for the establishment of Unimation (Europe) Ltd. in 1979. The National Research Development Corporation provided £ 420,000 ($592,000) in venture capital financing for Unimation (Europe) Ltd. More aid has been proposed, but is under question due to the takeover of Unimation by Westinghouse.[82]

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[81] "Jaguar Venture May Lead to Robots," *Automotive News*, Jan. 9, 1984.

[82] James Fleck, personal communication.

Other Countries

This section examines PA in Norway, Canada, Italy, and the Netherlands. Governments in each of these countries play a less prominent role in PA than the governments discussed above, and less information is available on their programs.

Norway

Direct Government Role

The extent of use of new technologies, as well as the general health of Norway's export sector and the relative price of Norwegian products, are and have been key problems for the nation's economy.[83] They have been the subject of a major study and planning efforts. Norwegian work environment programs are discussed in chapter 5.

The Lied Committee

In March 1978, the Lied Committee was appointed to study the structural problems facing the Norwegian economy and to identify areas of possible growth in Norwegian industry. While recommending a long-term strategy for Norwegian industrial development, the committee stressed that the role of the Government should be limited to providing sound macroeconomic conditions. The committee emphasized that it is not the Government's role to determine which firms or which types of industries should be given priority. Instead, it suggested that the decentralized market system, wherein individual firms make decisions based on what they predict will be profitable, should continue to prevail in Norway.

The committee suggested that the development of a long-term strategy should take into account the following conditions of Norwegian national resources:

- a considerable quantity of cheap electric power,
- full coverage of future needs for oil and natural gas,
- production of a considerable amount of oil and natural gas for export, and

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[83] Stein Berge, Second Secretary, Embassy of Norway, personal communication, Feb. 24, 1984.

- reasonable access to capital due to oil and natural gas export revenues.[84]

The committee also recommended that Norway concentrate on improving its export sector, mainly by lowering the cost of Norwegian goods relative to those of surrounding countries. This could be achieved through productivity increases, structural rationalization, minimization of wage increases, and tax adjustment.

The committee deemed the ability to apply new technological developments crucial to industrial expansion. It argued that the Government could create the proper conditions for technological diffusion through an expansion of the educational system to provide more engineers and qualified skilled workers. Finally, the committee recommended that the Government encourage the establishment of new industries based on new technologies. Though the Norwegian Government has generally accepted the recommendations of the Lied Committee, there has been no particular action based on the report.

The Norwegian Ministry of Local Government and Labor

A working group of the Norwegian Ministry of Local Government and Labor reported to the Ministry in 1980 on the potential effects of steadily increasing factory automation on employment and working conditions in the 1980's. The working group predicted that automated materials handling systems will allow the Norwegian wood-processing industry to reduce its labor force by 50 percent by 1985. It also predicted that the number of computerized numerically controlled (CNC) machine tools will increase in the machining industry, as will the application of robots for welding and spray-painting.[85]

The working group pointed out that while there is a wide range of possible applications for information technology in industry, these technologies are at different phases in their development and are being disseminated at different rates to different user groups. This makes it difficult to characterize the consequences for employment. In predicting the effects that factory automation will have on the Norwegian economy as a whole, the working group argued that continuous process and electronics industries have a greater potential for productivity gains than does the metalworking industry. Although firms may implement the new technologies, given the small and medium size of Norwegian firms it was predicted that the benefits will be limited.

Canada

Federal Support for Technology-Enhanced Productivity Program

CAN$10 million ($8 million) over 5 years has been committed to 10 microelectronics centers through the Federal STEP (Support for Technology-Enhanced Productivity) program. The STEP program is intended to help producers of microelectronics and advanced production equipment to develop products that will be competitive in international markets. It is also intended to help users implement the technology efficiently and develop new and improved products for the Canadian economy.

STEP incentives for producers include reimbursement of:

- up to 75 percent of eligible expenditures on R&D,
- up to 50 percent of eligible costs of machinery and equipment, and
- up to 15 percent of eligible costs of buildings.

STEP incentives for users include reimbursement for:

- feasibility studies—up to 100 percent of total costs, with a maximum of CAN $10,000 ($8,000);
- implementation of a new microelectronic product or process—up to CAN$100,000 ($80,000) or 75 percent of total costs; and

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[84] Norges Offentilge Utredninger, *Employment and Working Conditions in the 1980's*, NOU 1980:33.

[85] Ibid.

- design of custom microelectronic equipment—up to CAN$500,000 ($400,000) or 75 percent of total costs.[86]

Manpower Consultative Service—Education and Retraining

The Department of Employment and Immigration established the Manpower Consultative Service, a key mechanism for aiding workers displaced for economic, technological, or other reasons. The Service provides assistance to employers who work with their employees to reduce manpower levels or develop work force skills. In particular, it operates on an as-needed basis, becoming involved when mass layoffs are expected to occur, and supplementing local labor market institutions for brief (e.g., 6- to 12-month) periods.

The Manpower Consultative Service was founded in 1963 to encourage labor and management to work together on problems of worker displacement. The Service has a program whereby management and labor consult as equal partners in committees on matters of mutual concern, such as turnover, employment instability, working conditions, absenteeism, training requirements, and management studies. It provides up to 50 percent of the cost of the labor adjustment committee, and up to 50 percent of worker relocation costs if a committee transfers workers in order to keep them employed. Where new technology is the cause of displacement, the committees look at the impact on skill needs and try to develop means of counseling, retraining, and placement for those who are displaced. Both industrial training for work on new machinery or new job content and institutional training in trade schools are provided. In addition, subsidies are provided for older workers to train for new jobs. Companies do not always participate in the MCS program, as they are required to continue to pay the workers' fringe benefits during the transition period.[87]

The Ontario Board of Industrial Leadership and Development

The government of the Province of Ontario established the Board of Industrial Leadership and Development (BILD) in January 1981, comprised of cabinet ministers responsible for economic and regional development. It develops long-term investment strategies for the Ontario Government and funds programs through grants, loans, and other forms of assistance. The BILD program is budgeted at CAN$1.5 billion ($1.2 billion) over a 5-year period. Overall objectives of the BILD program are to develop an import replacement and export potential in order to improve Ontario's trade balance, technological development, training, and job creation.

The Board of Industrial Leadership and Development has recognized that new specialized skills will be required with the implementation of computer-assisted manufacturing. Under the Training in Business and Industry program, BILD subsidizes up to one-third of the cost of retraining workers, with the remainder paid by the worker and the employer. BILD also provides equipment grants to educational facilities, research grants, and career counseling services.

Under its high-technology development program, BILD has allocated CAN$100 million ($80 million) to five industry-oriented technology centers to provide expertise to companies applying new technologies. The five centers are described below:[88]

- *The Ontario Centre for Advanced Manufacturing.*—This center has two facilities; one for CAD and CAM in Cambridge, and one for robotics in Peterborough. Funding will be CAN$40 million ($32 million) over 5 years, beginning in 1983. These facilities will provide consultation services for the implementation of CAD and CAM and robotics, and will help individual firms tailor the technology to their needs.
- *The Ontario Centre for Microelectronics.*—This center, located in Ottawa, will receive CAN$20 million ($16 million) over 5 years. The center was opened on October 28, 1982.

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[86] "The News From BILD, Ontario," February 1983; and "Building Ontario in the 1980's," BILD, January 1981.

[87] Harry Monk, Employment and Immigration Department of Canada, personal communication, Dec. 9, 1983; and M. Bendick, Jr., "The Role of Public Program and Private Markets in Reemploying Workers Dislocated by Economic Change," The Urban Institute, November 1982.

[88] Brochure, "The News from BILD, Ontario," February 1983.

- *The Ontario Centre for Automotive Parts Technology.*—This center was established in order to encourage restructuring of the auto industry. CAN$14.5 million ($11.6 million) will be provided over 5 years for development of new product designs, market research, and management information services. The center was opened on December 14, 1982.
- *The Ontario Centre for Resource Machinery.*—This center will receive CAN$20 million ($16 million) to undertake R&D for the mining and forestry-equipment industries. The center was opened on December 15, 1982.
- *The Ontario Centre for Farm Equipment and Food Processing.*—This center will receive CAN$10 million ($8 million) over 5 years to undertake R&D. The center was opened on January 31, 1983.

Italy

Italy appears to have no specific policy to protect targeted industries or promote the movement of resources out of particular industries. However, the Italian Government owns a large share of certain industries (nuclear power, electrical components, telecommunications equipment, chemicals, steel, and shipbuilding) and financial institutions. The State has intervened in the economy with aid to industry in the postwar period, without an overall "industrial policy."

Most notable in Italy has been the government promotion of private investment in the underdeveloped southern regions. Investment grants, low interest loans, and tax breaks have been provided to private firms to encourage investment in the South, and State-owned firms have been required to invest in the South. Such investment has been encouraged in order to develop this region and provide employment to avoid the migration of Southern Italians to Northern Italy.[89]

The U.S. Robotic Industries Association (RIA) estimates Italy is the fifth largest robot producer but may become the third, after Japan and the United States, by 1990.[90] Robot use in Italy is particularly heavy in automobile manufacturing. Fiat, for example, is both a major user and developer of robotic systems. Olivetti, an office equipment manufacturer, is also heavily involved with PA.

The National Machine Tool Builders' Association estimates that Italy ranks fifth in machine tool production and third in machine tool exports, as of 1982.[91] There are close research ties among machine tool producer firms, and between producers and the Government. Research projects on manufacturing are sponsored by a financial agency (IMI) which channels low interest loans and Government-funded grants to small and medium-sized firms. The Italian National Council of Research has also begun a manufacturing research program which involves several Italian universities and industries.

The Netherlands

While the Netherlands is neither a major user nor producer of PA technologies, the Dutch are increasingly concerned with "catching up" in the development and application of PA. Industrial productivity is a source of great concern to the Dutch because 64 percent of industrial output is exported. There is concern, however, that automation could lead to a loss of industrial jobs. A study by the Netherlands Center for Technology Trends concluded that the gains in productivity that could be achieved by increased automation would outweigh the labor displacement because low productivity has made it difficult for Dutch products to compete with those of low-wage developing countries.[92]

The Dutch have several programs promoting or regulating the production and use of PA:

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[89] Lawrence Franko, *European Industrial Policy: Past, Present, and Future*, the Conference Board in Europe, February 1980, p. 34.

[90] RIA, Worldwide Robotics Survey and Directory, 1983.

[91] National Machine Tool Builders' Association, *1983-1984 Economic Handbook of the Machine Tool Industry*.

[92] I. H. Timmerman, *Automatisering in De Fabriek: Vertrekpunten Voor Beleid*, Delft University Press, 1983.

- The Ministry of Education and Science Policy and the Ministry of Economic Affairs launched an R&D program in October 1982 aimed at improving technological expertise and research potential at the technological universities.
- The Ministry of Economic Affairs is preparing a program for stimulating the PA industry. This program will include an awareness promotion campaign, provide subsidies and low interest loans to industry to promote investment in PA, and sponsor demonstration projects.
- The Ministry of Social Affairs will monitor employment and working environment impacts.
- The Ministry of Education and Science Policy, the Ministry of Economic Affairs, and the Netherlands Organization for Applied Scientific Research will administer education, training, and retraining programs.

Chapter 10

Policy Issues and Options

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Chapter 10

Policy Issues and Options

Introduction

The central policy question that emerges from OTA's computerized manufacturing automation assessment is, "Should there be a national strategy for the development and use of programmable automation (PA)?" Although such a strategy could take many forms, **the fact that the opportunities and problems posed by programmable automation are interconnected makes it appropriate to consider a policy strategy combining actions in several areas.** PA may well become an important factor in national productivity growth and improvement in economic performance, but the spread of this technology can aggravate existing social and economic problems as well as create new ones for individual regions and for the Nation as a whole. While the potential for PA to benefit industry and the economy counteracts arguments for slowing its spread, the risks inherent in rapid diffusion raise questions about whether, and how, the spread of PA should be accelerated. Among the principal motivations for policy are:

- **The immaturity of PA technology and limited experience with its application.** Although current technology is applicable in many situations, further development and applications experience are needed before its potential for improving productivity, work environment, and product quality can be fully realized.
- **The competitive environment in which PA development and use are taking place.** Governments in countries that are or may become U.S. trading partners are encouraging the development and use of PA abroad, while markets for many goods and services, including PA equipment and systems, are becoming increasingly international. Both situations militate against complacency.
- **The risk of growth in unemployment.** In the absence of growth in production levels, PA may be associated with unemployment, especially in the East North Central, Middle Atlantic, and other areas where PA use is expected to be heavy, and where local economies are vulnerable to import competition and other economic factors.
- **The risk of adverse effects on the psychological aspects of the work environment.** These effects, arising from the combined influences of new technology and job design, may not only diminish productivity gains from PA, but may constitute new health problems. Collective bargaining will allow only a fraction of the labor force to resolve these problems on their own. Because PA and structural changes in the economy will limit the number and range of manufacturing jobs available, many workers will become less able to move out of disagreeable situations.
- **The ramifications for education, training, and retraining at all levels.** The appropriateness of the mix of skills within the labor force governs both the rate at which PA can be developed and used, and the extent of adjustment (through retraining or relocation) that may be necessary given changing skill requirements. The challenges posed by PA and other new technologies come at a time when the capacities and resources of the instructional system are particularly strained.

As the above list indicates, there are factors that motivate policy promoting PA (technological immaturity and international competition) and factors that militate against accelerating PA adoption or that support complementary policy in other areas (the risks of worsening unemployment and work environments and the need to assure appropriate instructional capacities). Furthermore, concerns raised by PA are also aspects of larger policy problems. Competitiveness and unemployment, for example, reflect many circumstances, not just use of new technology. Assuaging these concerns, in particular, requires a healthy economy—something that PA can influence but not guarantee.

The remaining portions of this chapter will identify key groups of people with an interest in the use and impacts of PA and define existing and potential Federal roles. The chapter next adresses overall strategy for policy regarding PA. Then, current programs in the areas of technology development and use, work environment, employment, and education and training are outlined, and options for new policy are presented. The final four sections illustrate the types of policy that have emerged from more or less independent policymaking in each area, and they relate to existing legislation those options that could be combined into integrated strategies.

Stakeholders

Not surprisingly, the broad set of issues surrounding the spread of PA has aroused concern among a diverse group of stakeholders. Solving the problems associated with PA and realizing its potential benefits to the Nation will involve balancing the interests of the various players. Six principal groups are concerned about the shape of policy relating to programmable automation.

First, there are the **developers and producers of PA**, including the research community in both the public and private sectors and the manufacturers and vendors of PA equipment and systems. Engineers, computer scientists, and others in industry, academia, research institutions, and government are involved in developing, refining, and applying PA. As a group, they are concerned principally with the technical performance attributes of PA technologies; they tend to treat effects on the use of labor or the work environment as consequences rather than initial considerations. PA developers and producers are interested in the adequacy of funding and facilities for their work. They are also interested in the sources of funding and goals of R&D. PA manufacturers and vendors seek business climates that support the sale and effective use of PA.

Second, there are **the purchasers and users of PA**. Managers of manufacturing firms make decisions about research activity and the nature and type of equipment used in production. Concern with their ability to compete with other companies, especially foreign firms, translates into concerns for production efficiency, costs for labor and capital, product design, production processes, whether to make or buy components, and where to locate production. They consider a broad range of human resource issues, from job descriptions, hiring, promotion, and layoffs; to the scope and quality of education and training in local communities and the extent of training their firms offer; to labor-management relations and the scope of managerial control. As a group, they resist (and protest) Government intervention in production and personnel areas, while they call for better business climates.

Third, there are the **current and future members of the labor force**. These individuals care about whether they can get and keep jobs, and what kinds of jobs are open to them—by occupation and industry, by compensation level, and by degree of job security. They also care about the work environment implications of PA utilization, the type and location of PA applications, and trends in job design. And, they care about the amount, cost, quality, and sources of education and training available. Some labor force concerns are articulated by labor organizations (including unions), which are concerned in part with the potential for new technology to diminish their membership by reducing job opportunities in manufacturing or shifting them away from unionized industries. Unions have already begun to address various workplace concerns through collective bargaining and other activities. However, only about a fifth of the labor force currently can influence job design, job security, and training through collective bargaining. Hence, much of the current and future labor force lacks focused representation of their concerns, and this group may be the least well represented in private or public debates over PA and relevant policy.

Fourth, there are **communities and State and local governments**. These groups are particularly concerned about economic development and maintaining their employment bases. Because some communities depend on manufacturing for employment, and because they administer and fund education and training activities at least at lower levels, communities care about the rate and extent of PA production and use, along with associated changes in skill requirements, job mix, and instructional needs. Even though individual companies may adjust their work forces without layoffs (through attrition), decreases in company hiring may cause or aggravate employment and business problems for the local economy. Declines in employment and business levels may in turn give rise to a variety of problems for communities that range from increased health disorders to diminished tax revenues.

Fifth, there are **educators and trainers**. People who teach children and adolescents base curricula in part on expectations about employment opportunities and job design. People who teach adults also care about changes in skill requirements and industry hiring patterns; their planning and activities are especially sensitive to the rate of change, because the number of adult students is more subject to change than the number of younger students. Educators and trainers of all types are concerned about the funding, equipment, and facilities available to them. Currently, their concerns are likely to be heightened by the barrage of potentially conflicting demands and criticisms from numerous sources.

Sixth and finally, there is **the Federal Government**. Existing Federal programs suggest that the Government has broad interests in the development and use of PA. On the military side, the Government is concerned with the implications of PA development and use for national security and for reducing costs for defense products. On the civilian side, the Government has several concerns: It is concerned about levels of productivity, industrial well-being, and economic growth, which influence the standard of living of U.S. citizens; it is concerned about employment levels, which influence the income distribution, tax revenues, and expenditures for aid to individuals and regions; and it is concerned about equity issues, from occupational safety and health to the balance of power between labor and management. The Federal Government thus represents the interests of the Nation as a whole.

The Reasons for a Federal Role

Existing Federal programs reveal ample precedent for Federal involvement in the development and use of PA. In particular (and as described in more detail below), the U.S. Government already has a major role in funding PA research and development, and it offers tax incentives for capital investment that may motivate adoption of PA and other equipment. Moreover, it is involved in study and regulation of occupational safety and health impacts generally; it measures employment trends and relates them in limited degree to technological and economic developments; and it funds and shapes education, training, and retraining activities.

Both the nature of existing programs, and the fact that some of the benefits and costs of PA will accrue to the Nation as a whole, also suggest that the Federal Government has a stake in the diffusion of PA. The level of activity in PA production, for example, is a national issue. There is a limit to the amount of PA production the U.S. economy will support (even with low levels of imports and substantial exports). While policy at the State level fostering "high-tech" industrial activity may involve competition for a limited number of facilities, only Federal policy can affect the level of PA production nationwide. Also, international technological leadership, and its implications for national security, is a Federal concern; at issue are goals and conditions that transcend the interests and resources of individual companies, researchers, employees, and States.

Furthermore, there are equity issues which the Federal Government is best suited to address. First, adjustment assistance—whether in the form of extended unemployment compensation payments and other types of income maintenance, retraining, or relocation assistance—has long been a Federal responsibility. If PA or other influences, such as rising import levels, have adverse employment effects, the Federal Government will eventually pay to take care of individuals unable on their own to adjust to changing job opportunities. Second, work environment impacts seem to be social costs, like pollution, which market activity on its own will not control.* The labor market may be particularly ill-suited to handle both employment and work environment problems arising from PA in coming years for several reasons. In particular, the relatively slow rates of net job growth that economists expect will reduce the numbers of choices available to job-seekers.** Also, fear of displacement and limited union representation will diminish opportunities for workers to negotiate with management about working conditions or to seek other employment if dissatisfied. If industry does not move to alleviate adverse effects on the work environment, the Federal Government is in the best position to do so.

Finally, only the Federal Government is in a position to coordinate policy initiatives across a broad range of areas. The problem of coordination is not trivial. Current programs, which lack formal coordination, implicitly favor some interests over others by virtue of the allocation of funds and the breadth of participation in developing program objectives. Specifically, present programs (described in detail below) appear to favor the interests of PA developers and producers, and to a lesser extent, the users and their employees. For example, one Federal official involved with new-technology programs remarked to an OTA staff member, "I'm putting people out of work. Am I supposed to worry about that?" **While present policy allows programs to remain separate and parochial, only the Federal Government is empowered to assure that programs designed to address one area of national interest do not conflict with other national interests.**

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*According to Ruth Ruttenberg, former OSHA economist, "Occupational safety and health has become a public policy issue precisely because the economic system has failed to achieve an adequate solution to the problem of workplace hazards." "Regulation and the Economist," *The New York Times*, Nov. 20, 1983.

**While the economy will experience post-recessionary job growth, strong import competition, a high Federal deficit, slow population growth, and other factors are expected to constrain economic growth. See, for example: Alfred L. Malabre, Jr., "Some Economists Fear Room for Expansion is Less Than It Appears;" and Alan Murray, "Growing U.S. Trade Gap is Linked to Slowdown in Economic Growth." Both in *The Wall Street Journal*, Feb. 17, 1984.

The Challenge of New Policy

The diversity of issues and interested parties surrounding policy related to programmable automation suggests that Congress consider action in a variety of areas. However, in developing new policy, it is important to consider the context for actions in different arenas.

OTA's analysis suggests that the area where PA itself may motivate the greatest departure from past Federal policy is work environment. Because PA will eventually affect the work environment of most manufacturing personnel, especially in metalworking industries, and because it poses new problems pertaining to the psychological aspects of the work environment, the technology raises questions about the adequacy of existing mechanisms for studying, monitoring, and regulating conditions in the work environment. While this report only considers effects on the manufacturing work environment, the growing use of computer technologies across the economy may trigger similar concerns in other sectors.

By contrast, while OTA's analysis suggests new directions for Federal policy in employment and training, it also suggests that PA-motivated initiatives be related to broader forces for change in those areas. In the area of education, training, and retraining, OTA found that only some of the ramifications of PA could be isolated from the effects of increased use of new information and communication technologies generally across the economy. New technologies will affect goals for instruction at all levels, raising fundamental questions about educational objectives and the structure of the educational system. At the same time, shifts in the employment capacities of different industries (not necessarily due to new technology) may pose problems of obsolescent skills for specific occupational groups or local labor forces. These individuals, concentrated among production occupations, have special instructional needs largely unmet by the instructional system. Meanwhile, to minimize the risk of skills obsolescence in the future, it may be necessary to make fundamental changes in educational curricula and institutions, changes that better prepare individuals for labor market contingencies.

In considering employment policy, the principal problem associated with PA is how to minimize unemployment due to labor-saving technology and cope with employment adjustment without going so far as to postpone economic change and bring on problems far worse than might otherwise have occurred. Unfortunately, this cannot easily be achieved by shifting people from jobs among PA users to jobs among PA producers. PA producer jobs will continue to be fewer and much more "white collar" than typical manufacturing jobs have been. Moreover, because unemployment cannot generally be attributed to specific technologies, the "PA employment problem" is really the broader employment problem faced by the country as many factors, including growing import competition, are altering the employment potentials of different industries.

OTA's analysis also suggests that issues pertaining to PA development and use reflect broad policy concerns for technology development and transfer. PA provides tools for improving manufacturing processes and competitive strategies, but thorough evaluation of manufacturing processes, organization, and management, as well as more attention to competitive conduct (including product designs, pricing, and responsiveness to consumers), are necessary if companies are to make the most effective choice and use of any technology. There are many aspects of PA that require further development, but OTA found little evidence of critical research areas left unexplored, or that manufacturers were hindered from adopting PA because of insufficient technological development. Of greater immediate concern is the application of the technology. Timing is an important consideration for PA adoption because productivity improvement and other benefits of more efficient equipment and systems tend to lag their installation.

Federal Policy Strategies

The orchestration of policy initiatives in different areas may be considered a policy strategy. If the Federal Government chooses to coordinate activities in the areas of technology development and use, employment, work environment, and instruction, it can pursue one of four basic strategies: 1) laissez-faire, or a continuation of current activities; 2) technology-oriented, or emphasis on PA development and application; 3) human resource-oriented, or upfront attention to education and training, work environment, and job creation; or 4) both technology- and human resource-oriented. In each case, adjustment assistance may be required some time after the adoption of PA, though to varying degrees.*

The outcomes of Federal action can be evaluated according to likely effects on industrial output, employment, work environment, and change in adjustment assistance programs. The principal uncertainties that cloud projections of change are: 1) the rate of advance of the technology, i.e., the likelihood that the state of the art will advance far beyond what is currently expected during this decade; and 2) the relative success of efforts abroad to develop or apply PA and to increase sales penetration in domestic and foreign markets. Another major uncertainty is economic growth. A stagnant economy creates numerous problems which are best addressed directly, rather than through "PA policy," although initiatives discussed in this chapter may support a healthy economy. Federal action can influence all of these uncertainties.

The success of other countries in competing with U.S. firms (whether due to PA or not) can be a principal cause of lower industrial output and employment for the country. A strategy with at least some orientation to new technology development and use can reduce that risk, because it can contribute to improvements in productivity and competitiveness. However, a strategy that is strictly technology-oriented will probably increase the incidence of labor market problems associated with shifting employment demands, aggravating needs for retraining and other adjustment services. Even if greater use of PA were to make U.S. firms decisively more competitive, some firms may never hire to prior levels; some areas may depend primarily on such firms; and some individuals may have difficulty adapting to changing skill demands. Also, a strictly technology-oriented strategy is likely to aggravate potential work environment problems. In sum, a strictly technology-oriented strategy would entail upfront costs for technology development and use, but it would also entail other, postponed costs such as increased adjustment assistance spending.

A human resource-oriented strategy would involve investments in evaluating skill requirements; tailoring education, training, and retraining activities; and assisting in the matching of people with jobs. Ideally, it should avoid growth in adjustment assistance spending due to extended unemployment that might occur in the wake of PA, and it may even diminish such spending. Human resource development does not preclude and may well facilitate the use of PA and otherwise improve productivity. However, its effects on industrial output levels may not be as measurable as the effects of technology-oriented policy. Although human resource and technology initiatives may complement each other in influencing output and employment, explicit human resource efforts may be needed to address work environment concerns, regardless of whether initiatives are taken to accelerate PA application.

A combined technology- and human resource-oriented strategy could draw on the complementarity of equipment and humans in production, assuring technology development without compromising work environment concerns. Also, it lends itself to long-term job creation initiatives. Thus, a combined technology- and human resource-oriented strategy could assure that human impacts are explicitly considered in the processes of PA development and use. While this type of strategy is the most comprehensive and balanced, it may be the most difficult to design and implement because it explicitly affects the broadest range of interests.

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*The need for adjustment assistance is ongoing; it will never disappear totally in a dynamic economy, where economic and technological change continually create dislocations. That need normally varies in level, by geographic region, and over time.

Existing Federal Policy and Options for New Initiatives

The remaining portions of this chapter outline existing Federal policy in the areas of technology development and use, employment, work environment, and education and training. Each discussion of existing programs is followed by a set of options for possible policymaking in each area. These options could be combined to develop one of the strategies outlined above.

Existing Federal Policy for Technology Development and Use

Federal policy toward manufacturing technology for new products or production processes is piecemeal at best. Relevant programs principally address research and development, although both macroeconomic policies and more specific programs, such as tax credits, may indirectly stimulate technology change in manufacturing by encouraging capital investment. Only in the area of defense procurement does the Federal Government actively coordinate product and process technology development and application.*

As described in detail in chapter 8, Federal involvement in PA research and development comprises the efforts of four primary government agencies with distinctly different mandates. The work of the Department of Defense (DOD) and the National Aeronautics and Space Administration is heavily mission-oriented, although it may have significant spinoffs for the commercial sector. However, by and large the commercial markets for new manufacturing technologies tend to trail the Government (principally military) markets. The National Science Foundation (NSF) funds work of a more generic nature, and the National Bureau of Standards (NBS) performs significant generic work in its own laboratories. NBS performs research in many areas relevant to PA, including standardization in languages and in interfaces between computerized tools. In addition, NBS' Automated Manufacturing Research Facility, being constructed with DOD funding assistance, is one of the few full-scale test beds for computer-integrated manufacturing concepts.

The Federal Government is also involved in standard-setting. Standards in the United States are generally developed on a voluntary basis by vendors and consumers of specific products. The U.S. system of voluntary compliance with these standards contrasts with the government-enforced standards of many other countries. The role of the Federal Government, through NBS, is largely to follow and facilitate standards efforts, and in some cases perform supporting research.

Recent Legislative Proposals

Legislation has been proposed during the first session of the 98th Congress to provide direct support to the manufacturing sector in the United States. Many of these proposals include mechanisms for promoting greater cooperation between business, labor, and government for achieving national economic goals; a common theme is creation of a new institution. Such proposals include:

- The establishment of some type of National Technology Foundation or Board that would be charged with determining priorities for industrial development in the United States. It would assess the competitive capabilities of U.S. industries in order to direct national resources into those areas which would improve U.S. industrial performance.
- Some type of National Development Bank to finance the long-term development of targeted industries.
- The formation of a National Robot and Automated Manufacturing Leasing Corporation, which would facilitate the leasing of PA equipment.

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*Note that defense procurement technology programs described in ch. 8 are also complemented by the provisions of the Buy America Act of 1933, which stimulates domestic production by promoting procurement of domestically made goods by the Government.

- A National Center for Industrial Technology, promoting dissemination of manufacturing technology information.
- Special tax incentives for purchases of automated equipment.

Options for Technology Development and Diffusion Policy

Research and Development

Drawing on the existing set of institutions, Congress could act to increase PA R&D by influencing both the overall level of funding and the distribution of funding to various agencies and research topics. R&D contributes to the scope and level of technology available to the private and public sectors, and it contributes to the position of the country as a technological leader.

However, the degree of technological leadership to which we have become accustomed in the post-war era may not be sustainable. As one analyst notes:

> Thus, our present situation is that in many fields, America's earlier lonely eminence at numerous technological frontiers has given way to a world in which other industrial nations have attained positions close to, or at, these same frontiers. In many ways all this should be cause for rejoicing: We are no longer living in the readily-identifiable aftermath of the most destructive war in history. Although we are, perhaps understandably, preoccupied with the more purely competitive aspects of the situation, we need to be reminded that companionship at the technological frontier offers some considerable benefits as well as costs.*

Congress could act to maximize technological leadership in part by influencing both the overall level of Federal R&D funding and the distribution of funding to various agencies and research topics. The current environment for automation R&D is relatively healthy. However funding for more long-term, generic research in nonmilitary application areas is relatively thin. Congress may wish to raise funding specifically for generic research, primarily through the National Science Foundation and National Bureau of Standards. Several of the measures currently under consideration in Congress which increase Federal funding for engineering research, overall or for automation in particular, could serve as a vehicle for such an increase in nonmilitary PA research. The advantage of such a measure is that it could fill a gap in generic engineering research which has usually been too applied for major NSF funding and too basic for substantial industry attention. On the other hand, some would argue that such manufacturing-related R&D is the responsibility of industry.

Congress may also wish to increase the funding of specific areas of R&D, such as standards and human factors, which could facilitate the application of PA technologies. While a detailed assessment of funding allocations among the various topics of R&D is not within the scope of this OTA report, other studies have begun to address this issue.[1]

Standards

Standards are a means of increasing the ease of use of the technologies and encouraging their application. The principal disadvantage of standards proliferation is the risk that more rapid adoption of standards may provide short-term benefits for users but hinder future technological innovations which could be inconsistent with the standards. However, it is often the case that the products of a dominant vendor become de facto standards in the market. An increased Federal role may lead to a more reasoned choice of standard. Congress could stimulate standard-setting activities in the Federal Government by increasing or restructuring the funding of NBS, the agency which administers Federal standards efforts.

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*N. Rosenberg, Stanford University, "U.S. Technological Leadership and Foreign Competition, 'De te fabula narratur'?" November 1981, mimeo, National Academy of Sciences.

[1] See, for example: *Research Agenda for Increasing the Use of Computers in Design and Manufacturing*, Panel on Computers in Design and Manufacturing, Manufacturing Studies Board, National Academy of Engineering, October, 1983; "Recommendations for CAD/CAM Research Directions in the U.S.," Richard F. Riesenfeld, Department of Computer Science, University of Utah, prepared for the National Science Foundation, July 23, 1982.

Congress might also consider legislation which would clarify the legal position of standards-making groups. Currently, groups which help coordinate and oversee the intricate process of developing standards, such as professional and trade associations, can be held responsible for antitrust violations which specific standards may pose. A recent Supreme Court decision finding against a professional association appears to have significantly cooled private sector standards-making efforts, and it has helped make the process more time-consuming than usual.[2] While it is important that standards be devised so as to minimize potential anticompetitive effects, it may be possible to clarify the laws to reduce the amount of time involved in establishing standards.

In addition, Congress could consider providing a more active role for the Federal Government in standards development. Congress could direct NBS to increase its current efforts to facilitate, coordinate, and otherwise promote standard-setting efforts. A potential disadvantage of this option is that it would increase the Federal role in PA markets.

Diffusion

The appropriate rate for adoption of PA within and between industries is a subject of contention. It depends on the rates of adoption among U.S. trading partners, the extent of delay between invention and adoption of new technology, and the ability of the labor force and industries to adjust. In the past, adoption of individual PA technologies was slow, while it now appears to be accelerating. Thus, there is great danger in extrapolating from past conditions. In this context, there is probably a degree to which PA adoption can be facilitated without incurring excess costs. Beyond some indefinite point, however, encouragement of the use of PA may lead to ill-considered applications and excessive problems for employees and communities.

Congress could facilitate the adoption of PA by removing some of the barriers to application that have been cited by industry analysts and spokesmen. At the most general level, these barriers are the problems that industries traditionally cite as a hindrance to doing business, such as high interest rates and (high) taxes. Of course, such steps are not easy to take, and they may have side effects, including the creation of problems elsewhere due to the short-run loss of tax revenues.*

More specifically, Congress could consider legislation that would help to make relevant information available to businesses and communities. In particular, information about the nature of PA technologies and how their costs and benefits differ from those of other equipment would be particularly useful. Traditional modes of financial analysis are more suited to conventional equipment than to PA, and in consequence some firms have had difficulty justifying investments in PA.** Moreover, while trade and professional associations and journals do provide such information, that information tends to be incomplete. Congress could either empower a Federal agency such as the Department of Commerce to increase its efforts to collect and disseminate such information (e.g., through the National Technical Information Service (NTIS)), and/or foster cooperative arrangements between Federal agencies and relevant trade and professional associations. By complementing existing association activities with a Federal role, Congress could assure broader participation of interested parties, including employees and communities.

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[2] *American Society of Mechanical Engineers, Inc.* v. *Hydrolevel Corp.*, 456 U.S. 556, *reh'g denied*, 102 S.Ct. 3502 (1982).

*Overall economic policy in recent years has aimed at improving the performance of the U.S. manufacturing sector. Such policies have included increasing depreciation allowances for business investment in plant and equipment. The Economic Recovery Tax Act of 1981 (ERTA) provided generous allowances which were reduced somewhat in the Tax Equity and Fiscal Responsibility Act of 1982 (TEFRA). Despite these tax incentives, some analysts maintain that the large Federal deficit will continue to sustain high costs for capital.

**Conventional analyses often fail to capture changes in indirect costs, which tend to be invariant for alternative forms of conventional equipment. PA equipment may not only affect direct labor costs, but indirect labor, materials, and other costs as well.

Also, Congress could consider sponsoring demonstration programs, providing examples of best practice in the areas of technology and work environment. While PA installations in several companies are already well-publicized showcases, a Federal role would increase the likelihood that work environment and employment issues are clearly addressed and linked to the technology. On the other hand, the technology in any given installation can only represent the state of the art for a limited time in the context of relatively rapid change in PA costs, applications experience, and sophistication. Further, the investment and risk associated with a typical, retrofit installation of PA is far less than that associated with, for example, a synthetic fuels plant.[3] Thus, a demonstration program for these technologies may be less cost effective than for such technologies as synthetic fuels production. This gap may narrow, however, for large-scale experiments in computer-integrated manufacturing, which are far more costly and risky than "islands of automation."

Adoption of PA is only a partial solution to problems faced by the manufacturing sector. A longer term solution involves redressing the historical inattention, both of industry and government, to manufacturing processes, organization, and management. There is some evidence that this is happening already in the private sector, where international competition appears to have generated a new awareness of U.S. weaknesses. To assure that this awareness translates into effective actions, Congress could direct funding and effort toward the development of engineering curricula in universities which combine manufacturing, design, and human resource management activities, as well as research in manufacturing engineering topics.

Another approach with nearer term benefits would be for Congress to foster the creation of some form of "manufacturing institute," perhaps building on the research centers already at NBS or at universities to provide a focus for manufacturing technology, organization, and management issues. Such an institute could serve as an information clearinghouse. The National Academy of Sciences, for example, recently recommended establishment of at least one joint DOD-U.S. machine tool industry research center to improve flows of information supporting defense technology needs.[4] Yet, many observers believe that the need for improvement in technology transfer is greater in the civilian than in the defense sector. An institute could serve as a think tank serving all industries, with rotating fellowships bringing in people from throughout the manufacturing sector.*

The advantages of a manufacturing institute would depend on its structure and mandate. A potential disadvantage of an institute would be that it could become just another layer in a complex network of Federal and private organizations. Also, the designation of formal coordination requirements could freeze the extensive networking that already occurs informally. However, a Federal presence could assure broader participation in the networking process.

Existing Federal Employment Policy (Excluding Training)

The United States already has a variety of Federal employment programs and legislation. Most of the key pieces of legislation emerged during the Depression era. Excluding education and training programs, which are described later in this chapter, existing Federal employment policy covers four broad categories: 1) the development and distribution of labor-market information, 2) income maintenance for the unemployed, 3) labor standards, and 4) job creation.

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[3] See, for example, *Energy From Biological Processes* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-E-124, July 1980). Synfuel plants have been estimated to cost in the $2 billion to $3 billion range, while highly automated plants in discrete-manufacturing metalworking industries tend to cost under $1 billion. Levels of both technological and financial risk are very high for synfuel plants.

[4] Manufacturing Studies Board, Committee on the Machine Tool Industry, *The U.S. Machine Tool Industry and the Defense Industrial Base*, National Academy Press, 1983-84.

*The National Science Foundation has proposed a new program for 1985 to create five to ten centers for interdisciplinary engineering research. While these centers are in some ways similar to manufacturing "institutes," the relatively modest level of funding ($10 million for all five to ten centers), and the fact that they will not necessarily address topics related to manufacturing, indicates that they will not be likely to substantially change the historical U.S. inattention to manufacturing engineering.

Most Federal employment programs are oriented toward unemployment of relatively short duration, generally what is referred to as cyclical unemployment. Also, over the past two decades, Federal employment policy has come to focus on aiding disadvantaged groups of people (defined as low-income, or chronically un- or under-employed). Consequently, current programs are not designed to accommodate the more enduring unemployment that may befall individuals and communities given widespread technological change, growing import competition, and long-term shifts in consumer buying patterns—unemployment generally referred to as structural unemployment.

Compared to most European countries and Japan, labor market policy in the United States is reactive and uncoordinated, and it is not linked to other, industry-oriented programs for structural adjustment in the national economy. Since several recent reports by the Congressional Budget Office (CBO) and the Congressional Research Service (CRS) examine Federal employment policy in detail, this assessment will address key features and refer the reader to other analyses for more information.

Legislation

Major employment policy in general evolved from the following pieces of legislation: The **Wagner Peyser Act of 1933** established a free, public U.S. Employment Service (USES). USES (now called the Job Service in some States) comprises a State-Federal network of job listing and placement services. Unlike its foreign counterparts, however, USES does not have legal monopoly on job referrals, power to regulate competing private employment agencies, or power to compel its use by employers (except for Federal contractors). Because of these limitations, during the post-World War II era, USES became an outlet for relatively low-skilled, disadvantaged individuals. This occurred through the proliferation of specialized, private employment agencies which tended to serve relatively high-skilled personnel; the combined burdens of budget cuts and labor force growth; and the effects of a policy shift in the late 1960's which emphasized disadvantaged workers and which required USES and Unemployment Insurance (see below) officials to assist in the administration of public assistance programs. Since the 1960's, employers and employees have associated USES with welfare programs. Private employers consequently tend not to list openings with USES, except for lower skill, high turnover jobs. Thus, despite reforms and the development of computerized job banks, the USES has continued to play a marginal role in the labor market.[5]

The **Social Security Act of 1935** established the Unemployment Insurance (UI) system. It is a program administered by a Federal-State network of agencies which now covers most of the labor force. UI provides eligible persons with funds that replace up to 50 to 70 percent of their wages for 26 weeks. Associated extended benefits (EB) and Federal supplemental compensation (FSC) programs provide additional money over longer periods of time. Funds are generated by employer and employee contributions and disbursed through State agencies, with emergency allocations awarded on occasion by Congress. Labor-market analysts generally consider these and other payroll taxes incentives for employers to lay off personnel if business declines; the availability of unemployment compensation, together with the customary rehiring of laid-off personnel as business conditions improve, is generally considered to retard job-search efforts among the unemployed. However, the U.S. program has significantly lower wage-replacement rates than Japan, Germany, France, and Sweden.[6] *

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[5] The role of the USES and contrasts with its counterparts abroad are discussed in a monograph by Mike Podgursky of the University of Massachusetts (Amherst), entitled "Labor Market Policy and Structural Adjustment," Apr. 1, 1983.

Some countries provide public assistance to the long-term unemployed who have exhausted their UI benefits, and many European countries provide "short-time" (part-time or pro-rated) benefits to allow worksharing among firms and industries with reduced labor requirements. Some States, such as California, have recently begun similar worksharing programs. The Tax Equity and Fiscal Responsibility Act of 1982 called for the Department of Labor to develop model worksharing legislation for States.

The **Fair Labor Standards Act of 1938** (FLSA) provides specific standards for wages (including a minimum wage and overtime rates) and hours of work. It also prohibits child labor. FLSA covers primarily non-professional and managerial personnel. While collective bargaining in unionized settings provides a means of assuring that wages and working conditions are adequate, FLSA provides protections in the form of minimum standards for wages and hours for all workers.** It was intended, in part, to prevent individual State economies from profiting in trade with other States through lower labor costs obtained by low pay and/or long hours. According to observers, however, monitoring and enforcement of labor standards in nonunion workplaces tends to be limited. FLSA is complemented by other pieces of legislation governing wages and hours of personnel employed by companies doing business with the Federal Government. Those include the Walsh-Healy Act, the Service Contract Act, the Davis-Bacon Act, and the Federal Work Hours Act (which set the 8-day, 40-hour week as standard).

The **Employment Act of 1946** established a Federal interest in the adequacy of employment opportunities. The **Full Employment Act of 1978** expanded on the principles of the 1946 act, requiring that the President develop economic policy consistent with the achievement of full employment. Despite these legislative efforts to promote planning for the medium and long term, most employment policy and economic policy (fiscal and monetary) has focused on short-term objectives.*

Additional Programs

The legislation described above provides the framework for Federal labor market policy. Additional Federal programs aim at creating jobs, developing labor market information, and providing adjustment assistance beyond the UI income support program.

Job Creation.—Federal job creation activities fall into two categories. First, various **macroeconomic policies** aim to improve employment opportunities by stimulating aggregate demand (buying of various goods and services by all types of consumers) and production activity. The effect of such policies is indirect; relevant measures target interest rates, inflation, money supply, and disposable personal income, which in turn affect production and consumption activities by lowering costs and increasing budgets. While fiscal and monetary policy can aim for long-term economic growth, steps tend to be taken to improve short-term prospects as the business cycle changes. Macroeconomic policy is sometimes complemented by specific, short-term programs, such as the Public Service Employment Program of the late 1970's and various public works initiatives. Public works initiatives are recurrent themes in jobs legislation because of their countercyclical employment potential as well as their obvious appeal to constituents in affected areas. The Emergency Supplemental Appropriations for Jobs Act of 1983, for example, provided funds for a variety of public works projects. Public works programs can be designed to employ relatively high- or low-skilled personnel, although construction projects tend to employ relatively high-skilled personnel.

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[6] Ibid. Also, note that research by James Jondrow of the Center for Naval Analyses suggests that nonremunerative personnel costs (about half of which are fixed, mostly federally mandated or training-related) may account for about 23 percent of manufacturing employment costs.

*For more information on UI, see the analysis by CBO entitled "Unemployment Insurance: Financial Condition and Options for Change," June 1983.

**FLSA discourages, but does not prohibit, overtime.

*The development and aftermath of these laws are described in detail in a recent CRS analysis, "The Employment Act of 1946, as Amended, and the Opportunity for Economic Planning: The Federal Government's Response," Feb. 4, 1982.

A more focused program is the **Targeted Jobs Tax Credit** program. This program, initiated in 1978,* and amended by the Economic Recovery Tax Act of 1981 and the Tax Equity and Fiscal Responsibility Act of 1982, aims at job creation for economically disadvantaged groups. It provides employers with a percent of the earnings of a new hire in the form of a tax credit. The program has two principal shortcomings: First, there is a risk that employers will be paid for jobs that they would have created anyway. Recent modifications to the program are believed to have lessened this risk. Second, the program only applies to those firms that have tax liabilities, because the credit is nonrefundable.**

Labor-Market Information.—Various programs aim to generate labor-market information (LMI), although the Federal role in this area has been decreasing. The Department of Labor administers the Federal-State LMI program through the Employment and Training Administration, the Bureau of Labor Statistics (BLS), and the State Employment Security Agency (SESA) LMI units. The National Occupational Information Coordinating Committee (NOICC) and the related State committee (SOICC) network provide coordination, cooperation, and communication in developing occupational information. BLS, in particular, provides information on aggregate, industry, and occupational employment and wage patterns.

Because BLS has experienced sharp budget cuts during the current administration, it has cut back on the volume and precision of the information it publishes. For example, because the sample size for the Current Population Statistics survey has been reduced, results for small areas (including the smallest States) and minority groups are less accurate;* the elimination of the labor turnover survey means the loss of a leading indicator of manufacturing expansion and contraction; the elimination of the multiple jobholder supplement survey means the loss of a measure of the income adequacy of certain types of jobs; the elimination of the Family Budget program means the loss of a measure of economic conditions; and the cutbacks in the economic growth, productivity, and occupational outlook programs mean the loss of detailed insights into the changing deployment of labor in the economy.**

Adjustment Assistance.—Finally, in addition to the general employment programs listed above, the United States also has more focused adjustment programs. Prominent among them is the **Trade Adjustment Assistance** (TAA) program, launched by the Trade Expansion Act of 1962 and modified on several occasions, which has been the principal source of aid for displaced workers. The United States is unique among developed countries in distinguishing import-based displacement from other sources; European and Japanese programs encompass persons displaced by a variety of factors, such as new technology. Eligibility for TAA is limited to those who can demonstrate that they were displaced as a result of imports, although the strictness of the test has varied.

Due to strict eligibility criteria, TAA disbursements were negligible until the act was amended in 1974. During the 1970's, critics faulted the program for delays in providing assistance, for emphasizing compensation over active adjustment assistance, for funding people who eventually returned to their original employer, and for narrowly designating who was affected by imports (e.g., prime manufacturers but not firms whose principal business was supplying them). For example, the General Accounting Office found that relatively few TAA participants used the relocation assistance feature, principally because participants were either unaware of the program or uninterested in it. The 1981 amendments (through the Omnibus Budget Reconciliation Act) again revised the eligibility test, making imports a "substantial cause" of job loss, while the 1982 amendments specified that imports should have "contributed importantly" to job loss. The 1982 legislation provided very little funding, and the simple 2-year extension of the program enacted in October 1983 provided no funding.*[7]

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*It succeeded the New Jobs Tax Credit enacted in May 1977.

**These credits are discussed in a recent analysis by CRS, entitled "Jobs Legislation in the 98th Congress" (Issue Brief IB83059).

*Sampling and inferences for minority groups have always been suspect; the recent cutbacks aggravate a nonoptimal situation.

**The nature and ramifications of these cutbacks are described in a detailed analysis of Federal statistical programs prepared by CRS, entitled "Recent Changes in the Statistical Activity of the Federal Government," June 2, 1982.

There have been several Federal programs legislated to provide **compensation and/or other assistance to select groups of people** in the event of job loss resulting from Federal actions. These include the Redwoods Act of 1978 (compensating for job loss associated with the expansion of the Redwoods National Park), the Rail Passenger Services Act of 1970 and the Rational Rail Reorganization Act of 1978 (compensating for job loss associated with the rationalization of the national railroad system following the financial collapse of several railroads), the Airline Deregulation Act of 1978 (compensating for job loss associated with the deregulation of passenger airlines), and the Department of Defense's Economic Adjustment Program (compensating for job loss associated with changing defense spending and siting decisions). Some analysts might also add such Federal efforts as the loan to the Lockheed Corp. and the loan guarantees to the Chrysler Corp. during the 1970's as special programs aimed at averting massive unemployment (among other goals). And, there are various efforts providing preferential assistance to veterans (whose career development is at least interrupted by military service).

There are also programs targeted toward specific areas, such as the Defense Manpower Policy #4, which encourages defense contracts to be awarded to labor-surplus areas. The Area Redevelopment Act and its progeny also stimulated economic activity in specific areas, in part to promote employment. Current interest in enterprise zones, favored by the Reagan administration, also focuses on area development to stimulate employment.

Recent Legislative Proposals

A variety of employment bills were introduced during the first session of the 98th Congress. The number and content of the bills reflect the strong concern about high levels of unemployment, and uncertainty as to the duration of those levels. One bill (S. 1286, the Manufacturing Sciences and Technology Research and Development Act of 1983) appears to have linked the development of new technology with work force adjustment. That bill directed the Secretary of Labor to devise experimental programs for retraining "displaced workers" to facilitate the utilization of advanced manufacturing technology. Other recent legislative proposals regarding employment include:

- establishment of a system of tax credits for employers who hire individuals eligible for FSC payments, or provide tax credits for people hiring for businesses in enterprise zones;
- establishment of public works programs of either specified or indeterminate duration;
- activities to stimulate employment of specific groups, including senior citizens, railroad employees, and employees of relatively small defense contractors;
- reform of immigration laws and procedures, which would influence the supply of labor to U.S. jobs;
- establishment of plant-closing notification and consultation procedures; and
- establishment of a youth minimum wage.

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*Several recent CRS and CBO publications address TAA. See, for example, the CRS paper, "Unemployment Compensation and Trade Adjustment Assistance: Changes Made by the 97th Congress," Nov. 23, 1982.

[7] See "Current National Developments," *Employment and Training Reporter*, Oct. 5, 1983; and "New Law Qualifies More for 'TAA', 'UI'," *Employment and Training Reporter*, Nov. 3, 1982.

Options for Employment Policy

Options for employment policy range from continuing current programs (the status quo) to adopting new measures in one of three general areas: job creation, collection and dissemination of relevant information, and adjustment assistance.

Status Quo

The programs outlined above (together with the education and training programs described elsewhere) constitute the status quo. As a package, these programs provide relatively limited Federal involvement in long-term employment change. They principally aim for maintenance of income for individual members of the labor force who become unemployed, or for employment of disadvantaged groups who tend to have difficulty obtaining jobs from the outset. Also, they allow U.S. companies to rely on quick and massive layoffs (sometimes with plant closings) when business declines. Companies can achieve relatively quick, large-scale movements of capital to more productive uses by closing unprofitable plants and building or acquiring more productive facilities. However, this practice causes employees and communities to bear most of the costs of economic adjustment. In contrast, companies abroad (e.g., large Japanese manufacturing firms) tend to adjust their work forces more slowly and through a wider range of measures.[9] That conduct involves slower movement of (and potentially lower returns on) capital resources, but distributes the adjustment burden more evenly among employees, managers, and investors.

Existing Federal labor market programs and institutions are ill-equipped to deal with long-term shifts in labor demand arising from technological and economic changes, and growing uncertainty in skill requirements. These factors may contribute to growth in long-term unemployment, including extended unemployment among groups other than the disadvantaged. Similarly, they are not designed to deal with large regional disparities in unemployment. This is a concern since at least the near-term employment effects of PA will be concentrated regionally. Under the status quo, the employee would bear most of the burden of employment change associated with PA; various levels of government bear, both directly and indirectly, some of the costs of unemployment that might occur.

Job Creation

While retraining prepares a work force for transition, job creation assures that people have work to do. It is appropriate to consider a Federal role in job creation, because job creation programs at the State level may merely sharpen interstate competition for a given number of jobs, shifting the location of job opportunities rather than generating new jobs overall. Since most job openings occur to replace departing personnel, past and proposed Federal programs for job creation aim to generate new jobs that represent growth in economic activity. The principal problem in developing a program to stimulate job creation is to avoid paying for jobs that employers would have created anyway, and to avoid shifting employment from one industry to another, either of which would diminish net job growth.* These problems have chronically plagued past public-service employment and job-creation incentive programs.

At the most general level, **expansionary macroeconomic policy**—including changes in the supply of money, interest rates, and tax rates—can lead to job creation by stimulating economic activity, although job development is not restricted to specific industries or locales. Also, macroeconomic policies that strengthen the dollar may make imports effectively less expensive than domestic products, discouraging growth in U.S. production.

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[9] James A. Orr, Haruo Shimada, and Atsushi Seike, "U.S.-Japan Comparative Study of Employment Adjustment," draft, U.S. Department of Labor and Japan Ministry of Labor, Nov. 9, 1982.

*For example, a 5¢ per gallon Federal surtax on gasoline was enacted through the Highway Improvement Act of 1982 to fund a countercyclical public works program. When the legislation was proposed, critics charged that the added cost of surface transportation would result in job losses elsewhere in the economy, including jobs associated with the distribution of goods by trucks.

At a less general level, Congress can foster and shape job creation primarily by legislating **specific measures to stimulate hiring**. In addition to tax credit programs such as the one already in effect, such measures include incentives for domestic production and, in the event of persistent labor surpluses, legislation for change in average work hours and increased production of so-called public goods and services. These measures are discussed below in general terms.

Congress can stimulate job creation by legislating financial incentives (or legislating an end to disincentives) for companies to produce (and buy supplies) within the United States, instead of overseas. The rationale for such incentives is that local production entails local employment. Harrison and Bluestone, for example, estimated that over 30 million jobs were lost during the 1970's to plant closings overall, including the relocation of production to overseas locations. Other analysts have come to similar conclusions.[9] The risk of such incentives is that they can encourage inefficient production practices and lead to higher prices by sheltering domestic producers from competition from foreign firms. Economic theory holds that where domestic production is less efficient than production abroad, U.S. consumers will pay more for domestically produced goods; also, they will pay more for foreign-produced goods whose availability is artificially depressed. Consequently, producers and consumers will have fewer resources available to them to put to other uses. Employment may be sheltered in the short term but foregone in the long term. This argument is frequently raised by economists against import restrictions such as tariffs and quotas.[*]

Two types of job-creation programs might be considered in the face of persistent labor surpluses. The first is legislation to reduce average working hours (either tied to FLSA or as independent legislation, perhaps designed so that reductions in work hours are triggered by certain economic conditions), and the second would be legislation stimulating production of so-called public goods and services. Products like defense or perhaps childcare, for which there is recognized public demand which the private market is ill-suited or unable to meet, fall into this realm.

The chief benefit of **reducing average work hours** is that it would allow a given amount of work to be shared among a larger group of people. The number of jobs available is a function of the (average) number of hours per job, as is the amount of leisure time available to citizens. The tradeoff between jobs and hours is not a new policy concept; one of the goals of FLSA was to increase employment by discouraging employers from resorting to overtime work by requiring them to pay more for longer hours. Both economic hardship (due to low pay and unemployment) and technological displacement were concerns during the Depression era, when FLSA was enacted.[10] Another argument, first raised during the late 1970's, is that reducing work hours offers a way to avoid disproportionate job loss among female and minority employees, who often have relatively low levels of seniority.

Reducing the average hours of work is not necessarily the same as "work-sharing," which tends to involve the redistribution of existing work. The difference is important in contemplating income effects. A major perceived disadvantage of programs that reduce work hours is that individual employees may experience real wage losses (see ch. 4). This is especially likely for work-sharing. Broader distribution of work without growth in total wages will not lead to the same generation of new jobs that can result from growth in wages and spending.

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[9] Mary Jane Bolle, "Plant Closings and Business Relocations," CRS Issue Brief IB83152, Sept. 27, 1983.

[*] Note that there may be noneconomic arguments for sheltering a domestic industry. Usually, those arguments center on national security—on claims that there is a national interest in assuring domestic knowhow and production capability for certain products, usually involving defense-related technology. The test of national interest is a difficult one to make, as evidenced by the controversy over recent Houdaille and NMTBA petitions for restrictions on machine tool imports.

[10] Irving Bernstein, *The Lean Years* (Boston: Houghton Mifflin Co., 1960).

Some people, however, will willingly trade reduced work-hours and lower pay for increased leisure time.[11]

Changes in work hours may also cause businesses to incur additional costs for changing their operations and procedures to deal with greater numbers of personnel and for increased spending on fringe benefits. Firms may also lose efficiency, if the workers "picked up" through work-sharing are not appropriately qualified.* On the other hand, companies may face lower UI tax liabilities, which often rise for companies that lay off personnel. Also, work-sharing may encourage greater reductions in force where there are administrative benefits to doing so. For example, while a 10-percent cutback might satisfy a company's financial needs, a 20-percent reduction tied to a move to a 4-day work week may be easier to administer.

The actual costs and benefits of reducing work hours depend on how a program is structured—how funded, how phased in, etc. The current UI system, for example, implies that higher wage personnel would lose more than lower wage personnel because UI replaces less of their wages. Also, the experience-rating system, under which employers with worse ratings bear more of the cost of UI than others, implies that low-rated employers might effectively shift their work-sharing costs to higher cost firms.

Already, several States have provided for temporary reductions in work hours as a means of preserving unemployment during slack periods. These programs typically involve a reduction in work week for participating companies and pro-rated UI benefits for nonworked days. While employees in declining industries and areas may benefit in the short term, longer term gains would require a program with broad coverage that could help shift people into stronger industries. This, in turn, would shift adjustment costs to a broader range of industries and individuals and away from communities and governments. For even distribution of costs and benefits, a nationwide, Federal program may be necessary. In the near term, Congress might at least consider further encouragement of temporary hours-reductions and work-sharing, including facilitating necessary adjustments in UI and other programs to allow for altered terms of unemployment.[12]

Stimulating production of so-called public goods and services would also create jobs. It is not a make-work option: The production of public goods and services does not have to be met by expanded public sector employment; as in the case of defense procurement, public investment can stimulate private sector employment. If the economy is incapable of employing available labor resources in the production of private goods and services—a condition that has not yet been established conclusively—it is possible to increase production of public goods without reducing production of private goods. As employment grows, demand for private goods may grow in turn, shifting the balance between production of private and public goods and services. An often unrecognized advantage is that public goods spending may raise productivity in private goods production. For example, highway building and improvement can lower trucking costs and thereby reduce costs to the consumer, while child-care services can free-up parents for employment (as well as lower transfer payments for unemployed, child-rearing parents).

The principal disadvantage of public goods programs historically has been the risk of diverting productive resources from private goods production. This charge has been leveled against defense programs, for example, which support a handful of industries and tend to employ relatively high-skill personnel. It was also raised during the 1982 debate over funding public works projects with an increase in the Federal gasoline tax, which was expected to reduce economic activity among a broad range of concerns depending on truck transportation and other heavy users of gasoline.

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[11] "20 Million Opt for Shorter Work Week," *Employment and Training Reporter*, Nov. 16, 1983.

*However, unqualified workers may be less able to benefit from or afford work-sharing, insofar as employers resist hiring them, or because the full time wages for their work are already low.

[12] Judith Cummings, "Novel Ways Being Used to Save Jobs," *The New York Times*, Jan. 28, 1983. Also, as noted above, TEFRA mandated study of work-sharing by the Department of Labor.

Labor-Market Information

Because programmable automation offers the prospect of radical and ongoing changes in the deployment of labor, expanded collection and analysis of occupational employment data would provide a means of measuring the rate, extent, and direction of change within and between occupational groups. At present, it is not possible to compare detailed occupational data over short periods of time (e.g., 1 to 3 years). Also, official analyses of the effects of technology change on employment levels and staffing patterns are few and far between. Better data collection by the Department of Labor and the Bureau of the Census would improve the modeling exercises (using input-output analysis) already undertaken by those Federal agencies to describe and forecast employment trends, and it would improve the information disseminated to educators, counselors, and individuals by the Department of Labor through the Occupational Outlook Program and the Dictionary of Occupational Titles. It would also provide data for measuring "best practice" among firms in deploying labor, information that would be useful to managers, labor organizations, and educators.

As Federal statistics programs have been cut back during the past few years, debate over the appropriate Federal role in the gathering and disseminating of various forms of data has grown. The minimalists hold that Federal efforts should be confined to meeting the specific needs and priorities of government agencies. Their arguments are rooted in broader interests in deregulation and reducing government paperwork required of businesses. Supporters, by contrast, argue that agency needs and priorities change and are hard to predict or circumscribe; that private sources lack the wherewithal and authority of the Federal Government for collecting data; that there is a need for statistics that describe overall social and economic conditions across the Nation; and that there is a need for the Federal Government to provide citizens with information.[13] Limited funding for Federal statistics programs forces Federal agencies to channel resources to those activities of most immediate use by the Government, such as statistics describing overall employment and economic performance characteristics. This practice serves short-term information needs, but raises questions about the effectiveness of even the favored programs in the long term, because the most-used aggregate statistics depend on more detailed data-gathering, analysis, and modeling.

Adjustment Assistance (Excluding Training)

Public attention to Federal activity in adjustment assistance is growing because many States are affected; States are competing for jobs; and growing numbers of potentially affected workers are not covered by collective bargaining. Because those displaced by programmable automation are likely to have been at risk of displacement from other factors such as rising imports, expansion of overseas production, and plant closings generally, any Federal program of adjustment assistance would best be provided as part of a broader program to assist the long-term displaced; as experience with the Trade Adjustment Assistance program shows, it is difficult in practice to isolate single causes of displacement for determining eligibility for program participation.*

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[13] Daniel Melnick, "Recent Changes in the Coordination of Federal Statistical Data Collection.," Congressional Research Service, Sept. 15, 1982.

*A broad range of options for adjustment assistance programs has been evaluated in detail in recent publications by CBO, including "Dislocated Workers: Issues and Federal Options" (July 1982). As noted by CBO, a critical problem in structuring adjustment assistance programs is defining the target group. How eligibility for assistance is defined determines whether a program covers all categories of affected personnel ("vertical equity") and/or all people affected within categories ("horizontal equity"). Different criteria have different implications for client base size, cost, and coverage of people with varying capabilities for adjusting on their own. Table 74 shows the CBO comparison of different approaches to targeting adjustment assistance. Among the categories discussed in debates over programs (excluding retraining) for displaced workers include older workers (age 40 and older), workers in so-called declining industries, and workers in disadvantaged areas (including new entrants to the labor force).

Table 75.—Sensitivity of Estimated Numbers of Dislocated Workers in January 1983 to Alternative Eligibility Standards and Economic Assumptions

Eligibility criteria	Number of workers		
	High trend[a]	Middle trend[b]	Low trend[c]
Single criteria:			
Declining industry[d]	1,065	880	835
Multiple criteria:			
Declining industry and other unemployed in declining area[e]	2,165	1,785	1,700
Declining occupation[f]	1,360	1,150	1,095
Ten years or more of job tenure	835	710	675
More than 45 years of age	1,050	890	845
More than 26 weeks of unemployment	760	560	535
Declining industry[d] and ten years of job tenure	275	225	215
45 or more years of age	250	205	195
26 weeks of unemployment	145	110	100
Declining industry including other unemployed in declining areas[e] and ten years of job tenure	430	355	340
45 or more years of age	490	395	375
26 weeks of unemployment	330	255	245
Declining occupation and [f] ten years of job tenure	235	195	185
45 or more years of age	335	280	265
26 weeks of unemployment	165	120	105

[a] High trend assumes continuation of March 1980 to December 1982 growth rates in the number of unemployed workers in each category. Specifically, the number of workers unemployed from declining industries increased by 32 percent in this period—a monthly average of 1.4 percent.

[b] The middle trend assumes that the number of dislocated workers will remain constant from December 1981 to January 1983. The number of dislocated workers in December 1981 is estimated by adjusting March 1980 Current Population totals for changes in the level and composition of unemployment through December 1981.

[c] The low trend assumes that the number of dislocated workers in each category decreases proportionately with the projected change in the aggregate number of unemployed workers between the first quarter of 1982 and the first quarter of 1983, a reduction of nearly 5 percent.

[d] The declining industry category includes all job losers from industries with declining employment levels from 1978 to 1980. See Marc Bendick, Jr., and Judith Radlinski Devine, "Workers Dislocated by Economic Change: Is There A Need for Federal Employment and Training Assistance?"

[e] If a declining industry was located in an area defined as declining, all other job losers in the area were included. Declining areas are defined as those experiencing declines in population from 1970 to 1980 or with an 8.5 or higher percent unemployment rate in March 1980.

[f] The declining occupation category includes all job losers from occupations with declining employment levels from 1977 to 1980.

SOURCE: Congressional Budget Office, based on tabulations from the March 1980 Current Population Survey and other sources noted above.

While the debate over aid to displaced workers overall tends to focus on external aid, such as income maintenance or relocation assistance, the spread of programmable automation raises questions about the role of employers in the adjustment process. Two employer actions in particular might be encouraged by legislation. The first is advance notice of technological change and displacement, and the second is incentives for replacement of personnel by employers.

Advance notice of technological change allows workers to plan for change, evaluate training needs, and seek new work before a reduction in force is put into effect. It also allows management, communities, and labor to work together to ease the adjustment process. Nevertheless, companies often resist providing advance notice as an extension of the view that technological change is a management prerogative. The University of South Florida, for example, reports that its robotics experts have been asked to perform robot feasibility studies with the proviso that "under no circumstances are employees to find out."[14] A disadvantage borne by companies is that key personnel will often be the first to leave, possibly putting future operations in jeopardy. This concern has been a central argument in opposition to plant-closing legislation and to voluntary resignation (buy-out) programs.

Encouraging employers through financial incentives to replace personnel either within or outside of the firm is another option. This option, like job creation, increases the adjustment burden on companies relative to employees, communities, and local labor markets. It may stimulate cooperative activities among industry, local government, educators, and labor, perhaps building on efforts associated with the Jobs Training Partnership Act. On the other hand, it is primarily feasible for large employers, especially those with multiple facilities, broad product lines, and adequate training facilities and funds.

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[14] "USF Engineers Extending Robots' Limited Capabilities," Sue Stremmel, Oracle, June 15, 1983.

Existing Federal Work Environment Policies

The Federal Government already has policies that regulate the work environment, such as legislation covering wages and hours and occupational safety and health. These same policies will apply to the introduction and use of PA in manufacturing, although they may not be adequate to meet new concerns.

Legislation

The principal safety statute relevant to programmable automation is the **Occupational Safety and Health Act** of 1970. It has as its purpose to "assure so far as possible every working man and woman in the nation safe and healthful working conditions and to preserve our human resources." Under the provisions of the act, the Department of Labor is responsible for promulgating and enforcing occupational safety and health standards. The Occupational Safety and Health Administration (OSHA) was formed in April 1971 within the Department of Labor to implement the OSH Act. Additional legislation addresses worker safety in mining and atomic power environments. Traditionally, safety and health concerns in the workplace centered mainly on safety and protection from the most obvious exposures to toxic chemicals and other dangerous substances. More recently, greater emphasis has been placed upon occupational health, long-term exposure problems, job stress, and toxicological problems.[15]

Other laws focus on how employees and management may address work environment concerns. The **National Labor Relations Act** (NLRA) was passed in 1935 to encourage the practice of collective bargaining. The act was amended in 1947 (Taft-Hartley Act) and again in 1959 (Landrum-Griffin Act). The NLRA and its regulations govern the conduct of collective bargaining in the United States. With respect to the introduction of new technology, rulings to date by NLRB suggest that it is bargainable if the technology deprives employees of jobs, work opportunities, or otherwise causes a real change in working conditions.[16] Thus, the introduction of new technology may be treated similarly to decisions on whether to contract out work. Since the collective bargaining process directly benefits only workers in unionized settings, these protections may be lacking for workers in nonunion plants. The issue of coverage is important because, although unionization is relatively high in the metalworking industries, the use of programmable automation is increasing in a broad mix of industries. With current estimates of union membership in the United States totaling between 20 and 25 percent of all workers at most, there is a large segment of the population that will not be protected by the process of collective bargaining.

The Department of Labor administers programs to encourage labor-management cooperation on a number of issues. These programs take place in union and nonunion settings. Provisions are sometimes made in contracts for joint labor-management safety committes that meet periodically to discuss safety problems, to work out solutions, and to implement safety programs in the plant.[17] Insofar as labor organizations or workers perceive technology as a health issue (e.g., if there is substantial evidence to suggest that new forms of machine monitoring and pacing of work are unhealthy) labor representatives may push for measures to protect workers against such hazards.

Other Programs

The Department of Health and Human Services, through the National Institute for Occupational Safety and Health (NIOSH), is responsible for recommending new standards, conducting research on which new standards can be based, and implementing education and training programs for producing an adequate supply of manpower to carry out the purposes of the act. In addition to Federal involvement in the protection of workplace safety and health, there are agencies responsible at both the State and local levels as well.

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[15] Steven Deutsch, "Extending Workplace Democracy: Struggles to Come in Job Safety and Health," *Labor Studies Journal*, vol. 6, No. 1, Spring 1981, p.?

[16] See *Automation and the Workplace: Selected Labor, Education, and Training Issues* (Washington, DC.: U.S. Congress, Office of Technology Assessment, OTA-TM-CIT-25, March 1983), p. 55.

[17] *Characteristics of Major Collective Bargaining Agreements*, Jan. 1, 1980.

Options for Work Environment Policy

Congressional policy considerations with respect to the effects of programmable automation on the work environment fall largely in two areas. One is assuring that sufficient data are available to make informed judgments about current or prospective impacts of PA on workers and the workplace. The second area is determining whether current policy is sufficient to cover the health and safety aspects of the new technology. If Congress decides to act in these areas, options that warrant consideration include: maintaining the status quo, monitoring the workplace effects of PA more closely, increasing support for social impacts research, supporting new workplace standards, and considering broader workplace legislation.

No Increased Federal Role

Congress could choose to take no additional action on the workplace effects of PA. Although no single policy instrument specifically addresses the impacts of PA on the work environment, various mechanisms (including collective bargaining, OSHA regulations, and others) are already in place at the Federal, State, and local levels that cover workplace concerns in general, particularly in the areas of health and safety. In addition, PA is being introduced at a time when there is increasing awareness of and sensitivity to the effects of the introduction of new technology in all facets of American life.

There are some efforts in both the public and private sectors to plan for the workplace consequences of new technology, sometimes involving both management and labor. Such cooperative efforts are often tied to broader quality of work life programs and increased worker participation in decisions that affect their workplace. Two examples of joint efforts include arrangements between AT&T and the Communications Workers of America, and between the United Auto Workers and Ford Motor Co. Such programs are often restricted, however, to large, unionized companies. Similar opportunities may not be available to workers in small shops or nonunionized environments, primarily due to the requirements for associated time, effort, and cost . In addition, it is often the case that the traditional, adversarial postures of management and labor limit increases in cooperation and worker participation in decisions concerning increased automation. Concern for the displacement effects of PA may make employees reluctant to contribute to planning for PA.

The principal advantage of maintaining the status quo rather than initiating additional policy at this time is that congressional action on the workplace effects of PA may be premature. The technology and its applications are at an early stage of development, and the speed of its diffusion is uncertain. It is also difficult to know how many of the problems encountered in the workplace are transitional ones characteristic of any technological change. Consequently, there is a lack of data on the nature of the impacts of PA, especially over the long term. The information that exists is largely qualitative or anecdotal and often cannot be generalized for industry- or sector-wide responses.

Reliable information is critical if the OSH Act is to serve as the basis for PA-related work environment policy. The OSH Act is an enforcement statute which is implemented through investigations and measurements. While physical safety and health conditions tend to be relatively easy to measure objectively, psychological conditions are often less so. Broadening the scope of investigations would require additional investigator skills and procedures for which data on PA impacts would provide a foundation.

Additional Government action beyond the status quo could create mechanisms to collect data that would allow a more careful evaluation of the impacts of PA on the work environment, thereby permitting better planning to eliminate potentially serious problems. Both reliable data and better planning would contribute to a more focused development of policy initiatives over time, as appropriate. Without such Federal action, information on PA and the work environment will continue to be piecemeal and fragmentary, and anecdotal rather than quantitative. If use of the technology spreads more rapidly than expected, the United States may find itself reacting to the workplace effects of PA, rather than planning in advance to address its potential impacts.

Increase Oversight and Monitoring

Congress could increase the emphasis placed on the workplace effects of computerized manufacturing automation through its oversight and monitoring activities. Considerable attention has been given to these issues by a number of congressional committees over the past several years, particularly in oversight hearings. For example, in September 1981, the Subcommittee on Science, Research, and Technology of the House Committee on Science and Technology sponsored a series of hearings on "The Human Factor in Innovation and Productivity" which focused on new technology in the workplace.*

This type of activity increases the visibility of the subject and provides a public forum for information-sharing and presentation of diverse viewpoints. In addition to its own oversight activities, Congress could designate responsibilities for OSHA and NIOSH, such as monitoring and assessing the effects of PA on the work environment or evaluating the applicability of existing OSHA standards to computerized settings.

The advantage of this option is that it would provide a Federal approach to monitoring and assessing the impacts of PA on workers in all types of manufacturing settings—unionized and nonunionized, large and small. In addition, it would help to assure that Congress is kept aware of the most current thinking with respect to the impacts of PA on the work force. The principal disadvantage is that it could potentially result in a piecemeal effort with little or no coordination of activities or sharing of information. Thus, designation of authority, participation criteria, and accountability would be necessary in the design of an oversight and monitoring initiative.

Increase Support for Work Environment Research

Work environment ramifications of the use of PA are central to both its effectiveness and its other impacts. Congress could support research addressing such areas as the long- and short-term physical and psychological effects of PA, management strategies and policies in introducing and using PA, worker participation, identification of hazards and how to control them, skill changes, changes in work content and organization, and changes in organizational structure, among others. Wide dissemination of the results would improve the general level of understanding of practical ways in which PA technologies can be used to enhance the work environment. Research efforts could also lead to the development of models or guidelines for installations with favorable effects on the work environment which could be used by those who are contemplating or making changes. Demonstration projects, seminars, and experiments would enhance understanding of the effects of PA and the extent to which it can be shaped to improve the work environment.* Congress also could assure that all parties involved—managers, employees, educators, and equipment builders—would have timely access to relevant information.

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*The Congressional Research Service produced a committee print analyzing the testimony and discussion.

*Topics covered might include successful implementation efforts (and the other side of the coin—those that were not successful and why), innovative ways to organize work, and successful labor-management cooperative efforts.

Current research into the impacts of PA on the manufacturing work environment is modest in scope and support; funds for this purpose have been extremely limited. This situation has arisen in part because social science research funding is particularly vulnerable to reduction when funds are scarce. It has also arisen because work environment issues have traditionally not been major concerns to technology developers, industry, or even the social science research communities. Relevant research conducted by industry, universities, unions, and Government agencies is often piecemeal and short term. Human factors research, for example, is often narrowly defined to meet the performance needs of specific military (or industry) projects. Not surprisingly, therefore, there is no formal coordination of technology and work environment research efforts, nor evidence of a coherent plan or approach. By contrast, study of the impacts of new technology on the workplace is more common in Japan and Western Europe, where the subject has historically received more attention across sectors. In particular, many foreign countries combine work environment analysis with engineering research. To learn from their efforts and experience, Congress could direct an agency such as the Department of Labor to both survey relevant foreign activities and, in particular, to translate and disseminate foreign reports. However, recent cutbacks have already affected relevant research activities in the Employment and Training Administration and elsewhere in the Department of Labor.

Additional or redirected funding could be made available for activities administered by the National Science Foundation, NIOSH, the Department of Labor, or DOD to enable researchers to conduct both qualitative and quantitative research to determine the extent of the impacts of PA on the workplace. NSF would be in a position to extend the scope of relevant engineering research to include the social aspects of PA. It already funds separately relevant social science research. NIOSH could provide a perspective that would link and compare the safety and health aspects of PA to other occupational safety and health issues. The Department of Labor would be in a position to link the impacts of PA to other labor issues. DOD has already looked at some human factors issues in their ManTech program. In addition to individual agency efforts, increased interagency coordination of research efforts would have the advantage of combining the expertise of a variety of disciplines, e.g., engineering, sociology, and management.

In contemplating the Federal research budget, Congress may want to assure that work environment research, in particular, involves industry, labor, and academia together. Cooperative efforts provide academic researchers with access to a valuable source of data for analysis of long-term effects, while industry and labor may benefit directly from the findings in the short and long terms. Cooperative programs for research carried out over a period of time rather than accomplished in a one-time visit would be particularly informative to policymakers. Such research might be supported by any of the agencies listed above.

One disadvantage of increased funding for social impact research is the potential burden it might place on companies and individuals to respond to requests for in-depth studies. Some strategy for securing the cooperation of both labor and management would be needed to minimize potential burdens. The participation of professional and trade associations as well as labor organizations in the planning and execution of such research could help in overcoming some of the difficulties that might arise in gaining access to research sites.

New Standards

Both the framework and the mandate exist in the OSH Act for safeguarding occupational safety and health of Americans. If it were established that PA creates new occupational safety and health hazards that were not adequately addressed by manufacturers and users, new OSHA standards might be required. The previous two options, monitoring and additional research, are prerequisites to this option. Reliable information would be needed on the numbers of people at risk, on the nature of the risks, and on the costs of establishing new regulations.

Advance Notice

Congress may wish to propose legislation that would require employers to give advance notice of any technological change that will affect the working conditions of its employees. A number of union contracts include a clause covering such notice, and such clauses are becoming more common. Legislation would especially benefit and protect employees of firms that are not unionized. Advance notice can benefit employees by providing time for them to plan for the change (possibly in cooperation with employers, communities, and educators) and to update their skills if required; it provides employees with the means and the responsibility to plan for change. It also provides the opportunity for employees to participate in some of the decisionmaking that directly affects their work, if employers wish to involve them in this way. While advanced notice of technological change might be as controversial as advance notice of plant closings, the potential costs for workers and managers would likely be smaller. (See above discussion under employment policy.)

Omnibus Work Environment Legislation

Although the United States already has a statutory framework for protecting occupational safety and health, other aspects of the introduction of new technology in the workplace, such as the potential for monitoring and surveillance and the need for advance notice of technological change, suggest the desirability of taking a broader approach to work environment policy. In addition, a broader approach would ensure that the interests of all workers would be protected, given the limited coverage of collective bargaining.

A number of European countries have taken an omnibus approach to workplace concerns. In Norway and Sweden, for instance, work environment legislation has been in effect since 1977. One of the purposes of this legislation is to protect workers' mental as well as physical health in the workplace, particularly in the context of technology change, and to give employees an opportunity to influence the design of the work environment. Such legislation elevates these concerns to policy levels, and provides a framework for more concrete actions, such as those described below.

An American approach to legislation has been proposed by the International Association of Machinists, which has drafted a Technology Bill of Rights to "amend and redefine official labor policy" (see table 52).[18] In addition to advocating the use of new technology to promote full employment, this proposed measure includes such work environment safeguards as prohibiting monitoring and surveillance of workers, advance notice of technological change, and requirements for training. The Technology Bill of Rights has been made available by IAM to local unions for guidance in collective bargaining. Because of its breadth, however, if such a Bill of Rights were enacted as an amendment to U.S. labor laws, enforcement would be difficult.

Workplace legislation could establish a clear institutional focus for work environment concerns to enhance the general appreciation of these issues and their contribution to the economy and society. One example of such an institution is the Swedish Work Environment Fund, which provides funds for research and development in the work environment, addressing aspects of both physical and mental health. Its function is to collect and disseminate information, and to coordinate relevant program efforts. Financial support is provided by a variety of sources, including the government, employers, and workers. Such an institution might be considered for the United States, which presently has only limited institutional involvement in the work environment area, concentrated on protection of physical health and safety.

The principal advantage of an institution of this kind is that it provides a coordinated focus for workplace research, and it establishes the workplace as an area of national concern. It would help to overcome much of the fragmentation of workplace research efforts currently evident in the United States by providing a central thrust and source for dissemination of information, demonstration projects, etc.

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[18] "Let's Rebuild America," IAM, p. 195.

Existing Federal Education, Training, and Retraining Policy

At present, instruction for PA is funded through a variety of public and private sources. Federal funding of education, training, and retraining efforts of this type is authorized under broad legislation designed to encourage career awareness and occupation-related instruction on the elementary, secondary, and postsecondary levels.

The Federal role in education has traditionally been that of supplementing or enhancing State and local activities. However, in recent years, there has been a movement toward lessening direct Federal involvement with the establishment of educational block grants to States in place of categorical grants targeted for use with particular population groups or in specific types of programs. In spite of this trend, there are still many Federal laws that influence curriculum content and overall operations of local school systems and institutions of higher learning.

In contrast, the Federal role in training and retraining efforts—particularly for the economically disadvantaged—has been a dominant force since the 1960's. The enactment of the Manpower Development and Training Act (MDTA) and the establishment of a nationwide apprenticeship system did much to enhance the existing delivery system for training and retraining. In keeping with the trend toward decentralization, the recently enacted Job Training Partnership Act (Public Law 97-300) assigns responsibility for administration and regulation of federally funded training and retraining activities to the States.

For the purposes of this report, this section will briefly discuss in general terms selected Federal laws and proposed legislation that are present or potential sources of support for PA instructional programs.

Legislation

Elementary, Secondary, and Vocational Education.—The **Education Consolidation and Improvement Act of 1981** (ECIA) called for the creation of a block grant to States in lieu of over 40 separate categorical grants to elementary and secondary schools, many of which were directed at special populations such as the handicapped and the economically disadvantaged. The intent of ECIA is to afford greater flexibility to State agencies and local school systems in how Federal funds will be utilized in support of State and local priorities. The major criticism of the Educational Block Grant Program is that numerous State and local educational priorities must compete for the same funding pool. Funding authorized under the **Vocational Education Act of 1963**—legislation now being considered for reauthorization beyond 1984—represents approximately 10 percent of the resources. State and local education agencies designate funds for secondary and postsecondary vocational education and training.[10] Funds made available under the act are utilized by a variety of institutions, including vocational/technical schools operated by local school systems, State-operated skills centers, and community colleges. Among the typical expenditures allowable under State-administered vocational education programs are facilities maintenance and improvement, equipment purchase, and curriculum development.

Postsecondary Education.—**The Higher Education Act of 1968** authorizes Federal funds for use by public and private colleges and universities to supplement tuition proceeds, State funds, and private donations or endowments. Allowable expenditures under the act include facilities maintenance and improvement, equipment acquisition, and curriculum development.

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[10] Daniel M. Saks, "Jobs and Training," *Setting National Priorities: The 1984 Budget* (Washington, D.C.: The Brookings Institution, 1983), p. 165.

Since the 1960's, the Federal Government has operated **Student Financial Assistance Programs**—among them the Guaranteed Student Loan Program (GSL) and the Pell Grants. The original intent of these programs was to provide broader access to higher education for individuals from low- and middle-income families. However, increased default rates and concern for overall program expenditure levels ($3.1 billion in fiscal year 1983) led to recent congressional action to tighten eligibility by requiring all applicants to undergo financial needs analysis, regardless of income. The Pell Grants, the largest of the student financial assistance programs, is also currently undergoing reevaluation. Both GSL and the Pell Grants have been sources of financial assistance to students enrolled in public and private colleges and universities and postsecondary, proprietary business, and technical schools.

Private Sector Training and Retraining.—The recently enacted **Job Training Partnership Act** (JTPA) replaced as of October 1, 1983, the Comprehensive Employment and Training Act (CETA) as the legislation authorizing Federal involvement in occupational training and retraining. JTPA represents an expanded version of title VII of the CETA Amendments of 1968, known as the "Private Sector Initiative Program," designed to stimulate more direct business involvement in training, retraining, and employment of the economically disadvantaged. While the target audiences for programs designed and operated under JTPA are economically disadvantaged youth and adults who lack marketable job skills, title III of the act authorizes the expenditure of funds for retraining and related services for displaced workers. JTPA is administered at the State level, and programs are implemented through a network of local private industry councils that assess local needs and establish performance standards for training and retraining programs funded under the program. Unlike CETA, JTPA does not stipulate that living allowances will be provided to trainees under certain circumstances. Such provisions are left to the discretion of State legislatures.

Recent Legislative Proposals

Education, training, and retraining has been high on the list of priorities for both the 97th and 98th Congresses. This is due in part to concern over current and potential future work force effects of shifts in the industrial composition of the economy, and in part to the emergence of "excellence in education" as an issue of national concern. In addition, the rising national debt and reduced State and local revenues have generated considerable bipartisan support for reexamining the Federal role in education, training, and retraining. Recent legislative proposals with a bearing on instruction for programmable automation include the following:

- strengthening precollege science and math education by increasing the supply of qualified instructors and encouraging curriculum development;
- encouraging computer literacy through teacher education, the creation of incentives for placement of computer hardware and software in local school systems, curriculum development, research, and other means;
- stimulating improvement in adult literacy;
- providing assistance to the States to ensure that target populations such as the economically disadvantaged, the handicapped, men and women entering nontraditional occupations, veterans, and adults requiring training and retraining are adequately served by vocational education programs;
- creating tuition tax credits, and individual education and training accounts to stimulate greater individual participation in instruction; and
- creating tax incentives to encourage employers to provide additional training and retraining to employees as needed.

Options for Education, Training, and Retraining Policy

There is considerable pressure on the U.S. instructional system to be more responsive to structural economic change. Economic and technological change may well result in more frequent shifts in work force skill requirements, and it may well require greater flexibility and mobility among work force participants than ever before. The ramifications of PA for education and training are a subset of this larger issue. There may be a new mandate for the U.S. instructional system as a whole to gear education, training, and retraining programs of all types more to long-range, structural changes in the labor market. This focus, a change from the past orientation to relatively static occupational demands, will also require a heightened awareness of skills that are common to a variety of occupations—skills that, by their very nature, may provide individuals with greater occupational mobility. New approaches to curriculum design, more frequent review and modification of existing curricula in keeping with substantive labor market change, an increase in the supply of qualified instructors in some disciplines, and more attention to maintaining instructional facilities and using state-of-the-art equipment, will be necessary.

While industry, labor unions, and educators are all providers of PA-related training and other types of instruction, they have limited resources and sometimes hold different views of the nature and scope of instruction required, as well as the most appropriate modes of delivery. In light of these conditions, and the roles being assumed by industry and labor, the Federal role in education, training, and retraining needs to be reexamined. The following Federal policy options are proposed for consideration by Congress.

No Increased Federal Role

Congress could choose not to modify Federal involvement in education, training, and retraining in light of instructional needs associated with programmable automation. If this option were pursued, PA-related instructional requirements would compete with all others for Federal dollars earmarked for elementary, secondary, vocational, and higher education, and for training and retraining. Producers and vendors of PA equipment and systems would provide, as they do now, the bulk of initial training to employees of user firms.* Companies utilizing PA would or would not provide additional in-house instruction based on available corporate resources and priorities.** Community colleges and trade and technical schools, based on their varying readings of available labor market forecasts, student demand, familiarity with local labor market needs, and resources, would choose whether or not to develop PA-related degree and nondegree programs. Colleges and universities would, with existing resources, choose whether or not to adapt their engineering, computer science, business administration, and career guidance programs to the needs of automated manufacturing environments, based on their understanding of industry and/or student demand. In elementary and secondary education, creating an awareness of career opportunities in automated manufacturing and providing information on skills requirements would be left to the discretion of the school district, institution, or individual instructor.

The advantage of maintaining the existing Federal role in PA instruction is that programmable automation is still in the earliest stages of utilization. Little is known about how PA will change or modify skill requirements, affect job design, or trigger job loss, particularly over the long term. Current labor market forecasts shed little light on possible new career opportunities within automated manufacturing on which to base instructional priorities.

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*In the summer of 1982, OTA commissioned a survey of views of education, training, and retraining requirements associated with the use of programmable automation. Results of telephone interviews with producers of PA equipment and systems indicated that 93 percent of producer firms provide instruction for their customers, but that the training is narrowly focused and designed for use with a variety of occupational groups.

**The OTA-commissioned survey of views of PA-related education, training, and retraining requirements found that 40 percent of the representative manufacturing facilities contacted utilized some form of PA, and of this number, only 22 percent sponsored or conducted education and training for automated manufacturing. Among the plants currently not offering instruction of this type, only 18 percent indicated any plans to implement programs in the future. The most common reason cited was "low benefits relative to costs."

The disadvantage of not modifying Federal involvement in education, training and retraining for PA is that the Federal Government would forego potential roles unlikely to be assumed by other levels of government or the private sector, such as assisting in the coordination of instructional activities, ensuring that adequate labor market forecasts are developed and that information derived from such forecasts is actively disseminated to individuals, educators, and trainers. For example, State governments are unlikely to encourage instruction that increases individual mobility within the work force (and between States), although increased mobility may further national employment objectives. In addition, shortages of instructors, inadequate facilities and outdated equipment among traditional deliverers of technical instruction are national concerns. These conditions should be considered in determining possible Federal roles in instruction for programmable automation and in examining overall Federal involvement in education, training, and retraining.

Increase Support for Facilities, Equipment and Qualified Instructors

Congress could choose to build on the existing Federal role in elementary, secondary, and postsecondary education by targeting resources for the purchase or lease of state-of-the-art equipment and/or by making selected facilities ready for use in future periods of intense instructional demand. It could further increase instructional capacity by creating tax incentives that would encourage user firms to purchase state-of-the-art equipment and systems for training purposes and to expand their in-house instructional facilities. Congress is currently considering proposals to strengthen science and math instruction on the elementary, secondary, and postsecondary levels by improving curricula and stimulating more interest in teaching careers in these fields. It could also consider methods to encourage interest in careers in engineering education and other forms of technical instruction.

The advantage of these congressional actions is that upgrading facilities and equipment, as well as stimulating the supply of instructors, would remove the major barriers to the establishment of relevant instructional programs within the public and private sectors. Such actions would serve to shorten the time from the identification of new skill requirements to the development of instructional programs. Removing impediments to the timely design of instruction would be particularly valuable for displaced workers and others seeking to develop new skills or enhance existing skills quickly.

The disadvantage of congressional actions of this type is that they might stimulate too much interest in PA-related instruction at the expense of other types of education and training. Doing so would result in the establishment of excess capacity for PA-related skills development. In addition, there is the danger that facilities improvements and equipment purchases could overshadow attention given to needs assessment, curriculum design, and instructional program delivery.

Encourage Curriculum Development

Congress could choose to encourage the development of curricula for various educational levels and instructional programs geared to the development of PA-related skills, perhaps by fostering the development of voluntary guidelines for PA-related curriculum content. This could be accomplished by establishing a program within the Department of Education that would provide grants to educational institutions to develop model curricula. Alternatively, funds for relevant curriculum development could be designated within the existing program of Educational Block Grants to States. By encouraging industry and labor participation in curriculum development at all levels, and by encouraging intersector cooperation in defining instructional requirements and strategies generally, Congress could reinforce ties between industry, labor, and the instructional community.

Such congressional actions would create an environment for a new and coherent approach to curriculum design. At present, many programs for PA-related skills development consist simply of adding PA components to existing curricula. For example, a number of robotics maintenance and repair programs are based on long-established curricula for electromechanical technology or electronics. This approach to curriculum design is not necessarily ineffective; it simply needs to be examined and evaluated. However, curricula that are tied too closely to specific occupations may not stand the test of time, **particularly since present skills requirements associated with PA may represent only the first wave of change**. Encouraging comprehensive curriculum design and the establishment of voluntary guidelines for curriculum content would guarantee some degree of standardization to both enrollees and employers. Such standardization would foster the development of common skills that would, in turn, encourage more standardized approaches to job content and greater individual mobility within the work force. This would encourage proactive education and training.

The disadvantage of such congressional actions is that, unless carefully devised, they might stifle creative approaches to curriculum design and content that are ongoing or that might otherwise develop on the institutional level. There is also a risk that the importance of PA issues might be overemphasized in overall curriculum design.

Encourage Renewed Emphasis on Basic Skills and Problem-Solving Skills

Congress could choose to encourage at all levels of instruction a renewed emphasis on strong, basic skills in reading, math, and science. **Special emphasis could be placed on the development of individual problem-solving skills, since these are important prerequisites to training for careers in automated manufacturing, as well for nonmanufacturing occupations.** Many individuals are unable to participate in PA-related instruction due to basic skill deficiencies. Others have received technical instruction that was geared to the development of manual skills and that provided limited opportunities for the development of more abstract problem-solving abilities. Some have held jobs for long periods that did not require use of conceptual skills that may be more important for work in computerized settings. Congress could emphasize the importance of both basic skills and problem-solving skills at all levels of instruction, and take steps to coordinate basic-education programs for school-age youth and adults. This could be accomplished by strengthening the coordination function now performed by the Department of Education for elementary, secondary, vocational, technical, and higher education. Currently, the Department sponsors research on alternative approaches to basic skills and problem-solving skills development for different levels of education and for students of different age groups.

There are a number of advantages in pursuing this option. First, it can make the labor supply more resilient in the long-term by raising the overall skill level. Second, it creates a common foundation of skills that could be enhanced over time (as needed) through the development of job-related skills, including those associated with PA. Third, this approach does not feed the process of "skills obsolescence" by tying individual instruction too closely to specific technologies.

The disadvantage of this course of action is that it risks overemphasis of the basic skills to the neglect of broader educational experiences and the stimulation of career interests. In addition, it represents only part of a long-term solution, and it does not address the need for the development of specific, PA-related skills needed in the short-term, such as maintenance, repair, and programing.

Intensify Efforts to Gather and Broadly Disseminate Labor-Market Information

In order to adequately prepare for participation in the work force, individuals need access to current, reliable information on labor market trends, especially trends for occupational employment. Educational and career guidance personnel at all instructional levels, as well as individuals who provide job counseling and placement assistance to adults, also need access to current, reliable information. Congress could choose to strengthen the national database for labor-market information and encourage the development of strong links to State and local databases, where they exist. It could also encourage more systematic dissemination of labor market information, in cooperation with the private sector, by modifying the responsibilities of the Bureau of Labor Statistics and designating broad-based information dissemination as a primary BLS function. These actions would require an increase in appropriations, in light of recent cutbacks in Federal statistical programs.

One advantage of this type of congressional action is that it would enhance public and private sector knowledge of labor market conditions, facilitating "informed" planning by individuals, employers, educators, and all levels of government. Another advantage is that the database could be used in combination with information on industrial activity (e.g., plant and facility improvements) as an early warning system for major shifts in skills requirements in older or emerging growth industries.

The disadvantage of enhancing current labor-market information gathering and dissemination programs is that additional Federal expenditures would be required in a period of relatively limited Federal resources. The success of such a program would hinge on the close cooperation of industry and labor unions with the Federal Government in sharing information on emerging skills requirements and current approaches to job design.

Encourage Individual Participation in PA-Related Instruction

Congress could choose to influence the numbers of individuals who seek PA-related instruction or retraining for jobs in nonmanufacturing sectors. Measures such as those already being considered by Congress to make individual participation in instruction more economically feasible could be used to encourage PA-related skills development. These proposals include: the creation of individual tax incentives; the designation of training as an allowable expense under the Unemployment Insurance System; and the establishment of individual education or training accounts.

This course of action would increase the role of individuals in the adjustment process. Incentives to individuals would be particularly valuable in instances where employers do not provide PA-related skills development opportunities to their employees beyond the level of introductory training. Displaced workers who wish to pursue careers in computerized environments or elsewhere would gain the resources for acquiring necessary skills.

Possible disadvantages in congressional initiatives of this kind include overstimulation of individual interest in PA-related skills development that, unless carefully monitored, could result in a skills glut; proliferation of PA instructional programs that are not necessarily of high quality; and a disincentive to industries utilizing PA to provide employee instruction.

Encourage Industry-Based Instruction

Findings of an OTA-sponsored survey of views of instructional requirements for programmable automation suggest that the majority of firms currently utilizing computer-automated equipment and systems have no plans at this time to establish in-house instructional programs in the near future.[20] These findings are in keeping with ongoing, private sector concern about the high costs associated with providing in-house, technical instruction. Congress could choose to encourage users of programmable automation to establish or enhance existing, in-house technical training and education programs through the creation of tax incentives that help defray the costs of instructors, equipment, expansion of instructional facilities, and curriculum development.

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[20] For additional information on this OTA-sponsored survey, see *Automation and the Workplace: Selected Labor, Education, and Training Issues*, op. cit., March 1983.

This type of congressional action would stimulate additional training to meet short-term industrial needs. It would also encourage firms already providing PA-related instruction to broaden what is commonly very narrow course content; to provide access to training to a wide range of occupational groups—including production line workers; and to consider establishing longer range human resource development programs. Training associated with proprietary processes might be stimulated by the availability of additional resources. Incentives might be particularly useful in making training in small firms more structured and focused; it traditionally occurs informally on the job due to limited resources and other factors.

One risk of such congressional initiatives is that they may not assist manufacturing workers who need it the most: lower skilled production line workers and skilled craftsmen who have become unemployed or are at the greatest risk of job loss, since industry has traditionally provided little training to these worker groups. The design of specific initiatives would determine whether the unique needs of these worker groups are taken into account in instructional programs. There might also be a disincentive for some individuals to pursue PA-related education and training programs that are not offered by their employers.

Intensify Research Efforts

Since programmable technologies are still maturing and PA diffusion is still in the earliest phases, it is likely that additional changes in skill requirements for automated manufacturing will emerge over time. Congress could choose to increase Federal sponsorship of research to identify changing skills requirements within existing manufacturing occupations and emerging occupations, and to provide for broad-based dissemination of the findings to better equip educators and trainers for curriculum development. Congress could also use a research program to encourage the development of instructional standards that are in keeping with PA-related skill requirements. It could authorize the Departments of Education and Labor to establish mechanisms for regular review and reassessment of these standards by industry, labor, and educators. Strengthening the labor-market information database, as proposed in a previous option, is a prerequisite for this initiative.

Individuals, educators, industry, and labor would all benefit from an increased understanding of changing skills and emerging occupations, especially since little research of this kind is conducted within the private sector. Broad-based dissemination of this information by Federal and State governments, nonprofit associations, and other entities would ensure that workers of all types would have access and the opportunity to determine what it means in light of their career goals and skill levels. Over time, the availability of this information would give individuals and institutions a stronger basis from which to forecast future skills changes and to initiate instructional activities based on these changes. The creation of instructional standards would encourage the development of high-quality education, training, and retraining programs with content that accurately reflects industrial skills requirements.

A disadvantage to this option is that it would require an expanded Federal role in sociotechnical research in a period of limited Federal resources. Another disadvantage is that the creation of instructional standards could stifle creative approaches to curriculum content at the institutional level, and instructional responses to the needs of particular industries with unique PA applications.

Appendix

Appendix A

Selected Case Studies: Summaries

The following section includes summaries of five case studies of instructional programs designed to develop skills that are presently associated with the use of programmable automation (PA). These five are part of a group of 14 such studies developed for OTA. Instructional activities described in the case studies summarized here include: 1) a robotics and computer-aided drafting program for high school students, operated by the Oakland County School System in southeastern Michigan; 2) the undergraduate and graduate degree programs in Engineering Technology offered by Brigham Young University, Provo, Utah; 3) CADAM Inc.'s* customer training in computer-aided design; 4) the International Brotherhood of Electrical Workers' programmable controller training system; and 5) the "CAD/CAM" operator training program based in Glendale, Calif. (representative of efforts characterized by strong industry, education, and government cooperation). The five studies were selected for inclusion to illustrate PA-related instruction of various types and levels of sophistication, as well as to highlight programs operating in different geographic areas.

Case Study Research Methodology

Case study research began in July 1982 and ended in June 1983. The initial objective of the research project was to identify and contact a selected sample of institutions, organizations, and agencies known to offer or have the potential to offer programs designed to prepare individuals for jobs in computer-automated factory environments. Approximately 300 individuals representing industry, educational institutions, government agencies, professional associations, training and/or education associations, technical societies, and community organizations were contacted in the first stage of the research. This was augmented by a literature search. A sample of 100 training or education programs was identified, from which 20 were chosen to be the subjects of 14 case studies.

The following selection criteria were developed:

- *Geographical spread.*—Programs were chosen from all four quadrants of the country, with a concentration of four programs from the heavily industrialized areas of southeastern Michigan.
- *Instructional deliverers.*—The case studies include programs operated by primary schools, high schools, community colleges, universities, and 4-year colleges, a union/management-operated training center, and industries that produce and use PA equipment.
- *Type of programmable automation training.*—Programs chosen provide instruction in computer-aided drafting and design systems, robots, programmable controllers, computerized numerically controlled machines, automated vision systems for factory inspection, automated materials-handling systems, specialized semiconductor fabrication equipment, and CAD and CAM networking systems. In addition, university programs addressing the systems approach to computer-integrated manufacturing education, plus in-plant programs stressing the systems approach for managers, are included.
- *Occupational categories of trainees.*—Programs covered in the case study series address the needs of current or potential personnel in the following occupational categories: machine operators; electrical, mechanical, and other maintenance personnel; welders; electrical and electronics technicians; robotics technicians; mechanical designers and detailers; printed circuit designers; electrical drafters and designers; numerical control programers; general-purpose programers; integrated circuit designers; piping designers and drafters; manufacturing engineers; design engineers; systems engineers; research and development personnel; shop-floor supervisors; managers; and executives.
- *Size of institution or organization.*—Companies included range in size from firms employing under 170 individuals to multinational corporations employing hundreds of thousands of people. In terms of the size of the organization served by a single training division, the largest is 42,000. The educational institutions range in size from 2,500 to 34,000 students.
- *Funding source.*—Both public and private institutions and organizations are covered. Major public funding sources include Federal, State, and local government organizations.

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*CADAM Inc. is a subsidiary of the Lockheed Corp.

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The union/management-sponsored training program is supported by regular contributions from union members and by management subsidy.

- *Industrial sector.*—Programs covered addressed the following industrial sectors: transportation equipment (including auto and commercial aircraft); electrical and electronic devices and machinery; nonelectrical machinery; and programmable equipment producers. Attempts were also made to identify successful programs in the metalworking industry.

Additionally, some programs were chosen because they demonstrated cooperation among educational institutions, industries, and (in one instance) State and local government participation. Two questionnaires—one for companies and one for educational institutions—were designed for use during onsite interviews (lasting 2 to 5 days each) conducted for each case study.

Case Study 1

Oakland County Vocational Education Centers: Robotics and Computer-Aided Drafting For High School Students

Background/Summary

The Oakland County Intermediate School District covers approximately 900 square miles to the north and west of Detroit. The intermediate district is comprised of 28 constituent school districts and includes most of Oakland County and small proportions of the adjacent counties of Macomb, Wayne, Livingston, Genessee, Lapeer, and Washtenaw.* The approximately 211,000 children in the district live in communities of widely disparate economic status: some are among the wealthiest in the country, while others have disproportionate numbers of families on State and Federal aid.** In 1982, Pontiac, the largest constituent school district, had an unemployment rate of over 20 percent.

In 1967, voters in the intermediate district passed a half-mill levy to pay the construction costs for four area vocational education centers, one in each quarter of the county. The four centers—operated under contract to Oakland Schools by the constituent districts of Pontiac, Royal Oak, Walled Lake, and Clarkston—offer programs in 32 occupational areas. Three 2½ hour sessions—morning, early afternoon, and late afternoon—are offered for high school students, who spend the remainder of their school day at the "home" high schools; and the centers all operate evening classes for adults. The flexible vocational instruction offered at the centers complements the vocational education provided at high schools that operate individual vocational programs. The centers also provide basic-through-advanced instruction for students from schools that have no vocational programs of their own. Students who participate in a full 2-year course of study at a center get 900 hours of combined classroom and laboratory instruction in a specific vocational area.***

Oakland Schools also provides an additional aid to vocational programing in both the local districts and the regional centers: curriculum specialists on the vocational education staff at the Oakland County Service Center assist instructors in applying current instructional technology, in keeping program content up to date, in obtaining funds and equipment, and in maintaining contact with local industries.

In the summer of 1982, the Pontiac Center offered a special 4-week introductory robotics program for incoming juniors and seniors. The intensive 64-hour course was a demonstration program designed to test the feasibility of teaching robotics and other "high tech" courses in the centers' regular school-year and summer offerings. As a result of the successful summer program, robotics and computer-aided drafting are now taught in a number of regular courses in three of the area centers.

The centers have approached the teaching of integrated manufacturing skill in a variety of ways: 1) teachers at the Pontiac Center have designed a semester-long course in robotics offered for the first time in January 1983; 2) the Royal Oak Center has obtained two computer-aided drafting stations for use in mechanical and architectural drafting courses, and instructors there are using homemade robots to teach basic robotics principles in fluid power and electronics courses; and 3) the Walled Lake Center also has a CAD system for use in its drafting program, and instructors are now using the Mini-Mover "teach robot"* from the Pontiac summer course to teach electronics, welding, industrial design and machine-shop students the fundamentals of robotics as these relate to the students' core disciplines.

Summer Robotics Program, North East Oakland Vocational Education Center (Pontiac, Mich.)

Planning and Development.—The summer robotics demonstration program was conceived during an informal conversation between a vocational education curriculum specialist from Oakland Schools Service Center and the principal of the Pontiac Vocational Education Center. Although the amount of time from initial conception (March 1982) to approval by the Oakland Schools' superintendent's committee (June 2, 1982) to program implementation (June 28) was short, the preplanning which enabled Oakland instructors, curriculum specialists, and administrators to create the program on such short notice had been going on for the past 10 years.

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*This is Oakland Schools, a brochure published by the Oakland Intermediate District, explains that "in Michigan, every local school district is a part of an intermediate district; there is no exempt territory. The intermediate school district is a regional educational service agency created by State law to carry out certain legal functions at the direction of the State Department of Education."

***This is Oakland Schools.*

***The number of hours in vocational education curricula is mandated by the State and is comparable to that offered in comprehensive high schools.

*Teach-robots are miniature, table-top electric robots useful for teaching programing and robot motions.

The preplanning began not with robotics itself but with an ad-hoc group of instructors and curriculum specialists meeting informally to explore the utilization of computer technology in the classroom. Five years ago, the computer group began preparing for robotics and other industrial applications of computer technology by making—and maintaining—industrial contacts, expanding their working knowledge of microcomputers and programmable controllers, and familiarizing themselves with robotics. All this, according to the curriculum specialist who spearheaded the group, was done in anticipation of the time when robotics would be recognized as a suitable subject for high school vocational education.

Because of the necessity of waiting for the proper moment when public interest in robotics would be high enough to encourage the Oakland Schools' superintendents' committee to pass on such a program proposal, the preplanning was necessarily informal. The years of informal planning, however, proved to be productive; when the board's approval was received in the beginning of June, the computer-group members were able to bring together a team of teachers with expertise in electronics, physics, machining, and computer programing who both devised the curriculum and delivered the instruction. The Service Center curriculum specialist and the Pontiac Center principal bought some equipment and contacted industrial representatives who donated or loaned the remainder and—with the help of the instructors—arranged for field trips to local user and producer firms and for guest lectures by application engineers, sociologists and others.

Goals.—The program was designed to meet two sets of objectives. The immediate instructional objectives were to familiarize the students with the fundamentals of robotics to help them make future career and educational decisions, and to increase their awareness of and interest in high technology in general. The long-range goals were: 1) to develop, implement, and make necessary modifications to the curricular materials with the object of providing them to secondary and postsecondary educational institutions offering robotics instruction; 2) to develop a core of people within the public educational system with knowledge of robotics; and 3) to demonstrate that a public educational organization is capable of initiating robotics programs in a timely fashion.

Administrative and Instructional Staff.—The summer program staff consisted of two administrators, five teachers, and three student programing aides. The chief administrator for the program, the principal of the Pontiac Center, was responsible for student enrollment, obtaining the equipment, arranging for the students to receive academic credit, and other administrative requirements; the Oakland Schools Service Center curriculum specialist coordinated all curricular activities. The team of five instructors developed the instructional materials and designed and delivered the coursework; and the student aides (two college students and one high school senior) were on hand to help with programing and writing software for the Apple computers used to interface with the small teach robots used in the course. All of the instructors had a minimum of 2,000 hours of industrial experience,[1] two were members of the Education Committee of Robotics International of the Society of Manufacturing Engineers, and some had experience teaching and writing curricula for colleges and other post-secondary institutions.

Facilities and Equipment.—Classes were held in a large classroom-laboratory in the Pontiac Center. Equipment used in the program included four desk-top teach robots (two of which were purchased, two of which were borrowed from distributors), six Apple computers, three cathode ray terminals (CRTs), two DEC writers (strike-on terminals) and electrical and electronic test equipment.

Student Selection.—Because approval for the program was received at the end of the regular school year (June 2), student selection procedures were highly informal. The program administrators discussed the program with the guidance counselors in all of the high schools served by the Pontiac Center. By the time the board's approval was announced, however, most of the high schools had started their final examination periods or had released their students for the summer. Schools in two large districts, Pontiac and Rochester, responded by announcing the program over their public address systems, requesting that all interested sophomores and juniors apply. Fifteen of the sixteen applicants were selected, and all but one completed the 4-week course. Interviewers looked for college-bound students with strong math and physics backgrounds and with some experience in electronics and/or computers. Approximately 75 percent of the applicants had the recommended background knowledge; the remainder of those admitted were chosen because of their high level of interest in the program. Of the 14 students who completed the program, one was female and one was from a minority group.

Curriculum.—Classroom and laboratory instruction was complemented by field trips to Pontiac Motors, ASEA's midwest robot facility, and a local robotics show. Students also heard guest lectures by industrial representatives from Pontiac Motor Division, ASEA, ETON Corp., and the Kasper Machine Co., and by two sociologists who talked about the social implications of robotics. The following topic areas were covered in lectures and reinforced by field trips, demonstrations, and laboratory experiments:

- *History and classification*—Factors influencing the growth of robotics in industry; manufacturing processes in which robots are utilized; definition and description of robots and their component parts; robot classifications (nonservo, point-to-point servo- controlled, and continuous-path servo-controlled); description of commercially available robots; and the potential areas of growth in robotics.
- *Simple machine process and robot terminology*—Description of simple machine functions and the relationship between robot design-and-function terminology and the basic terminology of machine design.
- *Basics of electricity and motor operation/control*—An introduction to selected fundamentals of electricity and electronics, specifically DC power distribution and simple DC circuits. Students learned to use basic instruments to monitor electrical power and to locate malfunctioning segments.
- *Micro-computer operation and programing*—Lectures and demonstrations of computer operation and practical experience in computer programing.
- *Robotic drive systems*—A segment in which students learned how to address the teach robots with standard computer programs and prepared specific programs for robot operation.
- *Robot applications*—Review of manufacturing operations related to robot applications and field trips to design and manufacturing facilities.
- *Opportunities in robotics*—Examination of the employment opportunities in the field of robotics; requirements of various job classifications as they relate to the individual's development of skills and academic knowledge.

Had the superintendent's committee approval been received earlier, the instructors would have attempted to add another 2-week segment covering pneumatics and hydraulics. Lack of time and difficulty in obtaining equipment, however, made this impossible.

Instructional Methods and Materials.—The choice of a team-teaching approach was dictated by the interdisciplinary nature of robotics itself and also by necessity—no one teacher in the Oakland system had all of the background knowledge and skills required to teach the full 4-week program. However, the team of instructors worked well together, and each individual member of the team enhanced his own knowledge of related fields while imparting his particular expertise to the students. The lead instructor—who was on hand at all times to teach specific class segments, guide the students through experiments, and to provide continuity as the course moved from segment to segment—was an electricity instructor employed full-time at the Pontiac Center. Industrial representatives taught the basics of robotics; a physics instructor taught the unit on simple machine processes and aided the students as they conducted physics experiments; an electronics instructor from the Walled Lake Center taught the segments on electricity and electronics; and a programing instructor from another intermediary district taught the basics of programing.

The first 2 days of the program consisted of introductory lectures, films, demonstrations, and a field trip to Pontiac Motors, where the students saw industrial robots in operation and visited the robotics training laboratory. From the third day through the end of the course, the majority of classtime was spent in practical laboratory work, progressing from experiments in basic physics and electricity through robot programing. Because of the limited time available for each segment and the students' impatience with lengthy explanations of a theoretical nature, the instructors had to condense all of the material and be highly selective in the presentation of some of the topics. The necessity to condense and select was most challenging in the 3-day electricity/electronics segment which, after an introductory lecture in basic electricity and the importance of electronics to the study of robotics, concentrated on DC power distribution and simple DC circuits.

As in the other segments of the course, the object in the electricity segment was to familiarize the students with some of the basic concepts and—most importantly—to whet their interest and encourage them to pursue studies providing them with more complete knowledge of the disciplines making up robotics.

The instructors also worked as a team to develop the curriculum and written materials for the course. Since no texts, manuals, or experiments appropriate to secondary-level teaching were available, the instructors—aided by the curriculum specialist and by experts from industry—developed laboratory manuals, experiments, a robotics glossary, and handouts defining and describing robot functions, components, and classifications. In addition, the instructors developed computer software for use by the students in programing experiments.

Student Evaluations of the Program.—In written evaluations, most students noted that they had enjoyed the class. The majority were impressed by the team-teaching approach and the opportunities for individualized instruction. A number stated that they intended to pursue robotics studies and some claimed that the course helped them to decide on a future career in robotics. Some students noted the lack of training in hydraulics and suggested that it should be included were the course to be repeated. The other criticism received was from two students who felt that the electricity segment was too theoretical.

The instructors are now considering methods of dealing with the electronics segment in future familiarization courses. Suggestions include: 1) placing the segment later in the course when students would be better able to understand its relevance; 2) making provisions for a supplemental class for those with no background in basic electricity; and 3) teaching electronics as it applies to robotics, rather than beginning with pure electricity/electronics.

All of those who completed the course received a half unit of credit, which was entered on their high school transcripts (one credit equals a full semester-long course).

Relationships With Industry.—In the spring of 1982, program administrators and members of the instructional team met with General Motors (GM) representatives from the Orion Plant (a new facility with over 160 robots, which, at the time, was under construction) and from Pontiac Motor Division to determine the feasibility and appropriateness of offering robotics on the secondary level. The GM representatives and other industrial contacts agreed that introductory courses in robotics on the secondary level would not only benefit the students by providing them with an orientation to the field, but benefit industry by raising public awareness and student interest.

These industrial contacts, made in the preproposal stage of the program, also proved to be fruitful in the curriculum planning and program operation stages. The Pontiac Motors representative not only worked with the instructors to develop the curriculum, but delivered the introductory lecture to the first class and arranged for a field trip to the Pontiac plant. Other industrial representatives from firms that produce, distribute, and use automated machinery donated time and equipment to the program. While no formal industrial advisory committee was established before the summer program was offered, the curriculum specialist who helped administer the program (who is also the vocational/technical coordinator for the Oakland district) has set up an informal committee to provide advice on present and future programs and coursework.

Relationships With Labor Unions.—Local labor unions were not involved in the summer program, primarily because school officials looked on the summer course as a test case which would help them to develop prototype curricular materials which, they felt, were needed before asking for union advice or participation. Before the downturn in the area economy, local labor and company officials actively recruited students from the vocational education centers in the district, so that school representatives believe that union participation in an advisory capacity would be appropriate for computer-aided manufacturing coursework. Vocational education representatives are now making informal contacts with union shopworkers and hope to increase the level of contact with local unions in the near future.

Results.—Apart from achieving its objective of providing the participating students with an orientation to robotics, the summer program had a number of other salutary results. As one of the country's first robotics programs on the secondary level, it generated a great deal of public interest and received coverage in local newspapers, on local television stations, and in publications like the *Manpower and Vocational Education Weekly* and publications of the American Vocational Association. This positive publicity not only helped to convince school board officials of the viability of high school programs in robotics and other high-technology areas, but generated the beginnings of a communications network between Oakland Schools and other high schools both in- and out-of-State. The vocational education curriculum specialist who coordinated the program has received over 60 letters and calls from high schools, colleges, universities, and industries from across the country, all of which are either interested in establishing programs or have already done so. The local publicity also increased student interest in other programs offered by the centers. The Pontiac Center, for example, attributes an increase in enrollment for its electricity course to interest engendered by the robotics program. Enrollment increased from 35 in fall 1981 to 50 (capacity enrollment for two sections) in fall 1982.

Another result of the program can be seen in the current offerings of three of the Oakland vocational education centers (discussed in sec. II) and in a number of local high schools in the constituent districts served by the centers. The equipment purchased for the summer program is now in use in two of the centers. Most of the instructors who participated in the program brought robotics into their regular school-year classes (either as a segment in existing courses or as a free-standing, semester-long course) in the centers or in local high schools; and other instructors in the centers are now offering or planning to offer coursework in robotics or computer-aided design. The summer program also helped Oakland School officials to set up an articulation process with local private schools, community colleges, universities, and three industrial robotics programs.

The district is setting up a formal articulation agreement with nearby Oakland Community College whereby students who take robotics coursework in the Oakland Schools will receive advanced standing in the college's robotics program. The articulation process with the other schools and programs is, to date, informal. Other tangible results include the curricular and instructional material developed by the summer instructors—manuals, instructional units (both lectures and experiments), computer software designed for student use, the robotics glossary, and a study analyzing the reading level required for currently available robotics texts. These materials, and the experience gained in developing them, are now being put to use in classroom and laboratories throughout the district and will be refined and expanded in the immediate future.

Case Study 2

Brigham Young University: The Education of Technologists

Summary/Background

The College of Engineering and Technology.—Brigham Young University (BYU)—with a main campus in Provo, Utah, and a campus in Hawaii—is the largest private university in the United States. Founded in 1875 as the Brigham Young Academy, an elementary school with 29 students, BYU currently has an enrollment of approximately 28,000 at its Provo campus and over 1,800 in Hawaii. While its primary intent is to provide undergraduate education, BYU does maintain a number of graduate programs on the master's and doctoral levels which have a combined graduate enrollment of 2,890.

Brigham Young University's College of Engineering and Technology has a total enrollment of approximately 3,400 students working on undergraduate and graduate degrees in six departments: chemical engineering, civil engineering, electrical engineering, mechanical engineering, industrial education, and technology. The four engineering departments offer traditionally structured undergraduate engineering programs and masters- and Ph. D.-level graduate degrees. The technology department offers three programs leading to the baccalaureate degree (manufacturing engineering technology, design engineering technology, and electronics engineering technology), and a master's program in computer-integrated manufacturing with program options in computer-aided manufacturing (CAM) and computer-aided design (CAD), and elective courses in computer-aided testing (CAT). In the fall semester of 1983, the technology department began to offer a graduate program leading to the degree of master of technology management.

Engineering Technology.—In 1967, BYU became the first educational institution in the country to receive accreditation from the Engineers Council for Professional Development (now known as the Accreditation Board for Engineering and Technology, or ABET) for its baccalaureate programs in manufacturing engineering technology and design engineering technology. In 1971, BYU's B.S. program in electronics engineering technology was also accredited by ABET.

While engineering technology is closely related to engineering—and while the education of engineers and technologists overlaps in many areas—there are significant differences between the two disciplines. BYU's College of Engineering and Technology offers the following definitions which clarify the distinctions:

- *Engineering* is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize economically the materials and forces of nature for the benefit of mankind.
- *Technology* is that part of the technological field which requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it occupies a position on the occupational spectrum between the craftsman and the engineer at the end of the spectrum closest to the engineer.[1]

Technologists, in essence, are applied engineers. This may at first seem to be a misnomer, since engineering is traditionally considered to be an applied discipline. However, a brief overview of developments in engineering education in the United States over the past 25 years clarifies the issue. When the U.S. space program began in the late 1950's and early 1960's, engineering schools began responding to the increased need for science-oriented courses by adding advanced courses in mathematics, physics, and chemistry to their curricula. In the process, traditional engineering laboratory courses in drafting, machining, and processing were dropped out of the curricula to make room for the more theoretical courses required to meet the needs of sophisticated space-age technology. As technical knowledge and applications multiplied, the gap spread between engineers, whose education was becoming increasingly theoretical, and technicians engaged in manufacturing and design occupations. Baccalaureate technology programs (some began as 2-year technician programs, while others were originally designed as 4-year programs) were created to bridge the occupational gap between the engineer and the technician.

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[1] Brochure, College of Engineering Sciences and Technology, p. 9.

According to BYU representatives, it is no longer possible for one person to master the skills and knowledge required to cover the spectrum from conceptualization to the manufacture of a final product. Now, the idea for a product often originates with marketing, engineering, or management; the engineers and technologists work as a team to develop the layout and detailed design and to test the prototype product. The technologist and engineer work together to plan, design, and test the machines or procedures for building a system or its components, and then the craftsmen and machine operators bring about the actual production.* In terms of theoretical orientation, the progression goes from abstract at the design research engineer's end, to highly practical at the technician's and craftsman's end. While the engineer, then, may be interested in **why** a system, product, or procedure performs so that he/she can create plans or designs, the technologist is concerned with **how** that system, product, or procedure performs so that the engineering plans can be applied in practice and are implemented in the most productive manner.

Engineering Technology Programs at BYU.—BYU's Technology Department has gained national prominence, especially among industrial employers, many of whom say that the technology graduates have precisely those skills most in demand by firms implementing computer-aided manufacturing, design, and applied electronics procedures. Created with industrial needs in mind, the technology programs at BYU were quick to incorporate computer-aided techniques and machinery. In the early 1970's, individual faculty members in the manufacturing and design programs began exploring ways of acquiring computer-aided equipment to enable them to integrate CAD and CAM into the undergraduate curricula, and they initiated a number of research projects. In addition, data communications and real-time computer control were developed.

One research project used group technology classifications to create what has now evolved into DCLASS—a computer program that classifies, organizes, and retrieves information to assist in process planning, material selection, circuit design, generation of time standards, and other industrial applications. DCLASS is now licensed by 20 companies for use in 50 plants, and revenues received from the sale of DCLASS licenses help to support continuing research into computer-aided manufacturing by BYU faculty and students. In 1977, the technology department instituted a master of science degree program in computer-aided manufacturing; the program has expanded over the years to encompass computer-aided design and computer-aided electronics testing and is now known as the Computer Integrated Manufacturing Program. The masters program and the undergraduate programs in manufacturing engineering technology and design engineering technology are the primary subjects of this study.*

In recent years, BYU's traditional engineering departments have been building their capacity in what they refer to as computer-assisted engineering** and have joined with the technology department to form the Computer Assisted Design, Engineering, and Manufacturing (CADEM) Committee to coordinate the use of computers within the College of Engineering and Technology and to increase communication and cooperation between departments.

Engineering Technology: Education and Research Activities

A common misperception by outside observers—including a number of BYU faculty and students outside the technology department—is that the department offers undergraduate programs in computer-aided design and manufacturing. Actually, however, while computer-aided methodologies and techniques are incorporated into the curricula of the three technology programs whenever appropriate, the programs themselves focus on providing students with a strong foundation in the basics of the three disciplines—design, manufacturing, and electronics—**augmented** by computer techniques currently in use in industry. It is at the master's level that the technology programs focus solidly on computer-aided manufacturing and design.

The incorporation of computer-aided techniques and coursework into the undergraduate curricula varies from program to program—reflecting 1) current industrial practices in the three disciplines; 2) the varying amount of conventional manufacturing and design skills required by the different disciplines; and 3) the availability of industrial equipment. Thus, the design curriculum is most suffused with computer-aided techniques and applications both because of the large amount of CAD equipment in the department and because of the rapid spread of computer-aided design in industrial settings.

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*The Accreditation Board for Engineering and Technology (ABET) also recognizes the necessity of engineers and technologists working together as a team in industrial projects. According to ABET representatives, it is for this reason that over 700 associate and bachelor level technology programs have been accredited since the 1960's.

*The electronics technology program currently lags behind the other two technology programs in incorporating computer-aided techniques. This parallels the relative lag of industry in computer-aided electronic testing. This program will therefore receive less attention in the present study.

**Computer-assisted engineering (CAE) is defined by BYU engineering faculty as "the application of computers to the whole range of calculation and simulation tasks needed for modern professional engineering," including finite element analysis and routines for optimization, linkage synthesis graphics, and numerical utility.

The manufacturing program, while it is provided with well-equipped labs, stresses conventional manufacturing techniques for the first 3 years of study to provide the foundation for the advanced computer-aided manufacturing techniques and applications taught in senior and graduate-level classes. The electronics program is the least involved in computer-aided applications—a reflection of the relatively late development of computer-aided testing (CAT) technology and difficulty in obtaining CAT and process instrumentation equipment.

Undergraduate Programs: Common Features.—*Goals.*—The particular goals and objectives of individual programs are discussed in the program descriptions. The technology department as a whole, however, has identified a number of goals which have a significant general impact on the curricula and instruction in all of the programs. Some general goals are to "educate the 'whole person' " by requiring students to take a broad variety of general education courses and to instill in the students a recognition of the necessity of "life-long learning." While life-long learning is, in the most basic sense, the responsibility of the individual, the graduate who stops learning rapidly becomes obsolete when he or she leaves school and enters a technical field. For this reason, the technology faculty places major emphasis on bolstering the students' commitments to learn how to learn on their own; to keep themselves apprised of new developments in their professional fields; and to continually update their skills and knowledge.

Faculty.—Two distinguishing features mark the members of the technology faculty. First, all have had significant industrial experience in their instructional fields. That experience ranges from a minimum of 3 to 5 years in industry to a maximum of 10 or more years. Second, while industrial experience is required of the faculty, doctoral degrees are not required. Of the 16 full-time faculty members, 6 have doctoral degrees and the remainder have masters' degrees in technology or engineering. Although the department actively encourages its faculty to engage in research and to publish the results, that research is often of a practical and applications-oriented nature.

Teaching Methods and Materials.—All of the technology programs emphasize practical experimentation and application of the theoretical material taught in the classroom. The programs require that approximately 50 percent of the students' time be spent in laboratory work. Comments by both students and faculty, however, indicate that many students spend more than the required amount of time in the laboratories, so that the ratio of lab work to class work may actually be higher than one-to-one. Another instructional method in the department is the assignment of actual industrial projects to undergraduate students. Instructors on the design faculty, for example, are frequently requested to use the school's CAD equipment to perform benchmark studies of company drawings to help them determine the efficiency of a CAD system for the company's particular purposes. The studies themselves are assigned as projects to upper-division design students, who thereby gain actual industrial experience.

Other advanced students participate in similarly practical research projects conducted or coordinated by department faculty. Several technology faculty members are now working on computer-aided learning techniques and instructional systems, one of which—the Computer Aided Simulation Training System (CAST)—is being developed for use in both industrial and educational manufacturing programs. When the CAST project is completed, the learning package will contain a total of 300 learning modules—each providing instruction on a specific manufacturing process. As these modules are developed, they are incorporated into the manufacturing curricula at BYU.

One problem facing the department is the unavailability of appropriate textbooks in the CAD, CAM, and applied electronics areas. Since textbooks on technology quickly become outdated, the department is continually looking for other ways of supplying students with written material. A "Group Technology Collection" has been established in the university library to give students access to the growing number of reports and articles on productivity, manufacturing processes, and new developments in hardware, software, computerized data bases, and other topics. In addition, copies of monographs discussing current topics in manufacturing and design are reproduced and distributed to students for their personal collections. Another "library" resource, although not textual, is a growing "parts library" containing a collection of manufactured parts, which are used in the classroom to illustrate the end-products of the manufacturing processes being studied.

Enrollment Trends.—Enrollment in technology department programs has tripled in the last 3 years. Currently, there are just under 1,000 students enrolled in the three undergraduate programs: approximately 210 in manufacturing, 220 in electronics, and over 550 in design. This poses a problem for the department and the university in that even the new facility will only be capable of accommodating 900 students. Consequently, a policy of "enrollment control" has been introduced on a university-wide basis. Since enrollments in all of the technology programs are increasing, and the manufacturing and electronics programs are expected to reach enrollments of up to 300 each within the next 5 years, the design program enrollment will be gradually reduced over the coming years. Of the approximately 1,000 students, fewer than 50 are women, and most of them are enrolled in the design program.* More detailed discussion of enrollment trends can be found in the program descriptions.

Cooperative Education.—The College of Engineering and Technology operates an active cooperative education program which gives students the opportunity to integrate their academic studies with periods of work experience. Some of the traditional engineering departments tend to discourage students from entering the cooperative education (co-op) program by structuring the curriculum into a lock-step sequence which creates difficulties for students who spend time off-campus.

The technology department, on the other hand, actively encourages its students to take advantage of the co-op program. Approximately 45 percent of the 128 students enrolled in the college's co-op program in 1981-82 were technology students who worked at such firms as Boeing, GE, General Dynamics, Ford Aerospace, Honeywell, Eaton-Kenway, and Westinghouse. Aside from the obvious advantage of obtaining practical experience to supplement academic knowledge and laboratory skills, a large number of technology students have the additional advantage of discovering through experience whether or not they want to accept the permanent job offers they usually receive from the co-op employers.

Ironically, the success of the co-op program has created a problem for the department in that a number of employers have tried to convince their co-op students to stay on with the firm rather than return to school to complete their degrees. Another problem, which is somewhat limiting to some technology students, is the geographical isolation of the Provo campus and the consequent necessity for over half of the co-op students to relocate temporarily to accept out-of-state employment.

Furthermore, a large number of BYU undergraduates are married—many with young families. These students, especially, find it difficult to accept an out-of-state co-op assignment. For these and other reasons—including competition from other schools, the downward trend in the economy (which has caused a number of firms to discontinue their co-op programs), and increasing pressure on the university to turn out graduates—the co-op program has tapered off in recent years from a peak of 285 students in 1979-80 to 128 in 1980-82. Nevertheless, it still receives the support of the college and the active participation of technology students.

Counseling and Career Guidance.—The university counseling center offers both group and individual counseling for students with personal or academic problems, and the engineering college advisement center provides specific advice on engineering and technology programs. The university also has a career education program that provides the following services: 1) courses on life planning and decisionmaking, career exploration, and employment strategies; 2) interest testing; and 3) academic and occupational counseling.

In spite of all of these formal counseling and guidance channels, some technology faculty members feel that a great deal of the students' time and money is wasted because they do not receive comprehensive interest- and ability-testing when they are admitted to the university. This lack is felt most keenly in the technology department, where a major portion of the undergraduates are transfer students from other colleges and departments. Although some of these students discover the technology department through regular counseling channels, the vast majority learn of the department and the content of its curricula almost by accident—through friends, chance conversations, or parties outside the University.

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*In recent years, BYU has been actively encouraging "equal opportunity and rights for women students." According to the technology department chairman, women who graduate from any of the department's programs will have an excellent chance of being hired because of equal employment opportunity programs. While the number of women in the design program is growing, many women drop out of the manufacturing program. Technology department faculty say that this is primarily because a number of women are uncomfortable with manufacturing laboratory work.

Manufacturing Engineering Technology.—Like its sister program in design technology, the manufacturing technology program was organized in 1960 and accredited by what is now known as ABET in 1967. The program was constructed in such a way that, over the years, it has been able to accommodate the industrial trend toward computer-assisted processes and equipment without significantly altering its original focus. At the same time, the program has been refined over the years to minimize duplication, improve the course sequence, establish meaningful prerequisites, and give students flexibility in choosing areas of concentration.

Both the instructional program and the major research projects of the faculty and students are characterized by a highly systematic approach. That approach relies on the following:

- *Definition* of the subject matter (in this case manufacturing), its essential elements, and the activities involved;
- *Identification* of the need for a program in manufacturing technology and the processes and approaches to be employed to meet that need; and
- *Classification* of the processes and components of manufacturing to form the basis of a systematic approach to teaching and research. The notion of classification as employed by the manufacturing faculty rests on the following description: "Classification not only assists the memory by arranging individual items into groups, but also expresses a relationship of things and leads to the discovery of their laws."[3] BYU's approach is based on an attempt to discover the laws governing manufacturing—including economic laws, laws of physics, metallurgy, control systems, etc.—define them, and teach them to the students.

BYU bases its manufacturing curriculum on a broad definition which encompasses the total manufacturing enterprise: "the series of interrelated activities and operations that involve product design, planning, producing, materials acquisition and control, quality assurance, management and marketing of discrete consumer and producer goods." Manufacturing activities are classified into nine categories: product design activity, marketing, management, material control, manufacturing engineering, finances and personnel, production, and quality assurance. While the curriculum at BYU focuses primarily on one of those activities—manufacturing engineering—it also attempts to provide a background in the others.

To create the manufacturing curriculum, faculty members drew on their own industrial experience, informal industrial contacts, and a number of formal surveys and studies to assess industrial need, opinions of manufacturing educators, and requirements of accreditation agencies. After an exhaustive evaluation of the manufacturing discipline, the faculty found that the major factor distinguishing manufacturing engineers from those in other disciplines is the ability to do manufacturing planning and estimating. That ability, in turn, is built on knowledge of materials and metallurgy, production tooling, quality assurance, production information and control systems, plant layout and material handling, manufacturing systems and management.

The core courses developed to form the basis of the manufacturing technology curriculum are, therefore, those which develop the skills and knowledge required for manufacturing planning and estimating.* These are supplemented by special education courses in economics, mathematics, statistics and computer science, physical science, and electronics and design technology which provide the students with basic knowledge of other manufacturing activities related to their discipline. Also required are general and liberal education courses.

Program Goals and Objectives.—The two major goals of the manufacturing engineering technology program are: 1) to give the students opportunities for individual development; and 2) to prepare them with the latest knowledge and skills needed to lead or supervise personnel engaged in manufacturing operations, and to help in the development of new products and processes.** To achieve those goals, students are provided with theoretical instruction linked to extensive application experience. The core coursework is planned around eight specific areas of study which correspond to the requirements for manufacturing planning and estimating discussed above. These eight areas are: 1) manufacturing planning, 2) manufacturing processes and materials, 3) manufacturing development, 4) production tool and machine design, 5) production planning and control, 6) plant layout and materials handling, 7) inspection and quality assurance, and 8) manufacturing management. Specific objectives have been developed for each area of study.

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[3] Dr. Dell Allen, Professor, Brigham Young University.

*To further refine the curriculum, the faculty conducted a survey of graduates of 13 manufacturing technology programs, their managers, and educators from the institutions offering the programs. Tabulated results of the survey were then evaluated by seven experts, who also voted on various performance objectives to be maintained in manufacturing curricula. These performance objectives were also incorporated into BYU manufacturing technology curricula.

**The following comment by a Bechtel Corp. representative should be noted: "The hard, cold, practical fact is that anyone with any type of engineering education will aspire to be called an engineer, and there is not the nice, clean interface that the educators think there is between the duties of the many people engaged in an engineering-oriented program, be it design, construction, manufacturing, or operations." (Quoted from *Engineering Technology Education Study Final Report*, p. 51.)

Space limitations preclude a full listing of the objectives listed under each area. The objectives for instruction in manufacturing planning, therefore, will serve as an example. Those objectives are as follows:

- To familiarize the student with the function of discrete component manufacturing systems and the characteristics, analysis, and synthesis of such systems with emphasis on computer-aided manufacturing planning.
- To aid the student in developing the ability to analyze parts and products for manufacturing feasibility, to plan process operations and sequence, to estimate manufacturing costs, and to select manufacturing tools, machines, and equipment.
- To explore the various technical aspects of automation and numerical control systems (including labor-management responsibilities); to give students experience in manual and computer-aided numerical control programing; and to give them experience working in local industries to solve manufacturing problems through the use of mechanization and automation.

Computer-aided processes and techniques are incorporated into the coursework when appropriate; it should again be stressed, however, that the undergraduate curriculum emphasizes and builds on conventional manufacturing techniques and processes which serve as a foundation for the study of computer-aided manufacturing.

Facilities and Equipment.—The manufacturing technology laboratories are distributed through four buildings on the campus. The laboratories—some of which are shared with the Mechanical Engineering and Industrial Education Departments—occupy over 15,000 square feet (total) and include facilities for machine-tool operations, fluid power experiments, casting processes, metal forming, metallurgy, quality assurance, materials science, welding, metal forming, and advanced welding. Also available are a CAD computer area and a large machine-tool-performance and CAM lab.

A comprehensive listing of the conventional and computer-aided equipment available to manufacturing technology students is not consistent with the space limitations of the present study. Following is a description of the major equipment items in the CAM Laboratory:

- a high-performance Evans and Sutherland graphics system for use in process simulation and material flow studies;
- fabrication equipment, including a 3-axis computer-controlled milling machine used for undergraduate instruction and for some prototype production, and a Sheldon CNC lathe equipped with an Allen Bradley controller;
- two material storage systems—an Eaton Kenway mini-load stacker and a White Company carousel unit—used in conjunction with the manufacturing program's plant layout and material-handling course. The two systems are also used for storage of tooling and in-process inventory;
- an ASEA industrial robot capable of welding, grinding, inspection, assembly and motor rewinding which is used in graduate and undergraduate projects; and
- a 3-axis Cordax Model 1000 coordinate inspection machine, which will soon be supplemented by in-process sensors—including laser scanning devices and equipment for measuring force, temperature, position, and velocity.

The CAM laboratory has three major uses: 1) teaching at both the undergraduate and graduate levels; 2) R&D conducted by faculty and students; and 3) demonstrations and seminars for faculty, students, and industrial visitors. All of the production machines in the laboratory are computer-controlled to facilitate the development of a demonstration system in which all of the equipment will be networked into a distributed manufacturing system via common databases. To develop the proposed integrated system, the students and staff are in the process of setting up a "CAM Mini-Lab" where they can test the integrated manufacturing process on a small scale before attempting to use the full-size industrial equipment. Current equipment in the Mini-Lab consists of the following:

- An *IBM-PC Graphic System* used to retrieve a given part shape from a data file and to modify the basic dimensions to the required configuration. The output is then scaled and plotted on a hard copy device.
- The part information is then transmitted directly to an *Apple CNC Lathe controller* that

retrieves the cutter path routines to make the part.

- *A Microbot robot* retrieves the part stock from an automatic storage and retrieval system and inserts this part in the lathe chuck.
- The part itself is then automatically produced on a *miniature CNC lathe.*

In the near future, a miniature computer-controlled milling machine, a turret punch for sheet metals, and a newly designed robot will be added to simulate a fully integrated production facility.

Curriculum.—Freshmen begin with a course on basic machine-tool operation and an overview of the primary processes and materials used in manufacturing. They are also required to take basic graphics or drafting courses from the design technology division and an "Introduction to Engineering and Technology" course required of all technology students. Sophomore- and junior-year studies focus primarily on the manufacturing processes courses that form the backbone of the curriculum. These processes include machining, welding, casting, forming, molding, and heat-treating, and are supplemented by "related" technical courses in material science, fluid power, and electronic control, and "supporting" courses in computer sciences, mathematics, physics, economics, and technical writing. Sophomores and juniors also take courses in quality assurance, production planning, and machine-tool performance.

While a number of the freshman- through junior-level courses include sections on computer-aided manufacturing techniques, machines, and processes—most notably, the numerical control course, which contains a lengthy section on computer-assisted programing—it is not until their senior year that students may begin to focus on the curriculum's "minor option" in computer-aided design or manufacturing. At that stage, manufacturing students interested in design or programing may take advanced CAD courses from the design section or computer programing courses from the computer science department. Those interested in computer-aided manufacturing may take courses in robotics, computer-aided materials handling, computer-aided manufacturing systems, advanced N/C programing, N/C software development, and group technology.

All of the manufacturing courses have an associated laboratory requirement, and students spend approximately 50 percent of their time in the laboratories applying the theoretical material learned in the classroom. All students are assigned a number of individual and group projects during the course of their studies. The projects are designed to foster analytical and creative problem-solving capabilities, to help the students understand the importance of proper design and good manufacturing planning, and to teach them how to work as part of a development or production team.

A number of these projects are conducted as part of a senior-level course titled "Manufacturing Development Lab," which is designed to be the culmination of the students' training. Students in this course are expected to use the concepts and skills learned in previous processes and planning courses to tool-up and produce usable products, to perform in-depth manufacturing analyses, or engage in other production and planning activities identical to those performed in industrial environments. Products produced by students in the development lab include an electrically driven wheat mill and parts for a miniaturized turret punch press to be used in the CAM Mini-Lab, together with feasibility studies on the manufacture of the press. Students have also participated in joint projects with industry on plant layout and materials handling, machinability studies, and group technology and material classification and coding studies.

Enrollment Trends.—Beginning with two students in 1960, the manufacturing technology program has shown a relatively steady enrollment growth over the past two decades. With a current enrollment of 180 students, the program is expected to reach its enrollment ceiling of 250 students by 1985. The manufacturing program has the lowest number of female students of all the technology programs (three women are currently enrolled) and the highest number of transfers from other departments. In fact, very few of the Manufacturing Technology students enter the program as freshmen; from 30 to 40 percent of the students transfer from one of the engineering departments while the remainder come from a variety of other colleges and departments throughout the university.

An ongoing project within the manufacturing section is the development and analysis of manufacturing student profiles. This study shows that most manufacturing students have had from three to five other majors before taking up manufacturing technology, have an average of 2 years of industrial experience, and are 26 years old when they graduate. A recent study of approximately 30 manufacturing seniors indicates a number of similarities among those studied: their major interests were in mechanical things, seeing things work, seeing how things work, technical production management and supervision, and computer programing. Asked to assess their own abilities, the students rated themselves high in inventive ability, visualization of interaction among various components of a process, ability to do practical, "hands-on" engineering, ability to organize and schedule projects, ability to make decisions when not all the facts are available, ability to work under pressure, and ability to work well with people.

Placement.—From 95 to 99 percent of each graduating class of manufacturing technologists find jobs in industry. Most graduates receive multiple job offers at starting salaries that show a steady increase year by year. Although current salary information is not available, surveys of 1980-81 graduates show an average starting salary of $23,500, with salaries ranging from $21,000 to $27,600.

The majority of graduates are employed in the automotive and aerospace industries, heavy equipment manufacturing, computer-related production, and firms producing high-technology ordnance materials. Among the companies most active in hiring BYU manufacturing technology graduates are IBM, Texas Instruments, Ford, John Deere, Caterpillar, General Dynamics, General Electric, Hughes, U.S. Steel, Hewlett Packard, Boeing, Lockheed, and Cummins Engine.

A large proportion of the graduates are hired as manufacturing engineers; others are classified as industrial engineers, process engineers, design engineers, quality-assurance engineers, research engineers, and production engineers. A significant number go directly into management—most as managers, some as management trainees. The remainder assume a variety of positions and are hired as trainers, estimators, N/C programers, systems analysts, technical service representatives, production schedulers, and lab technicians.

Design Engineering Technology.—The design technology program was not only the first technology program in the United States to award a baccalaureate degree in design and drafting* but also the first 4-year program to be certified at the engineering designer level by the American Institute for Design and Drafting (AIDD)** and, along with BYU's manufacturing technology program, the first 4-year technology program to be accredited by ABET.

As the field of industrial drafting and design adapted to computer-assisted techniques, the design technology faculty attempted, as best it could, to keep pace with the rapid industrial advances. By the early 1970's, students in the design technology program were using APT part-programing language to complete manual programing and batch processing exercises, keying the manually produced programs onto a Flexiwriter which produced machine control tapes that were then verified on a Gerber plotter. At the same time, faculty members were actively exploring ways of automating the design graphics processes in the program by making contacts with industrial representatives, keeping themselves informed of the latest processes and their potential, and attending and speaking at professional gatherings.

It was at one such professional meeting—an AIDD convention—that a design technology faculty member was approached by a representative of Applicon, a major turnkey computer graphics firm, who had been impressed by his presentation describing the design program's attempts to incorporate industrial techniques into its curriculum. As a result of that meeting, Applicon eventually donated a computer graphics system to the design program. The one-terminal Applicon system was installed in 1975 and the faculty began developing coursework to incorporate computer-aided design instruction into the curriculum.

During the past 8 years, the relationship between Applicon and BYU's design technology section has remained strong and has resulted in the donation of two new Applicon systems (one of which replaced the original, already-outdated, system). In addition, because of the curricular advances made possible by the use of the Applicon systems for instructional purposes, Computervision, GE-Calma, and other CAD systems have either been donated by the producers or provided at a minimal cost to the college (see section on Facilities and Equipment). The design curriculum currently taught at BYU would not have been possible had the faculty been less successful in maintaining industrial contacts and encouraging industry to donate equipment.

Program Goals and Objectives.—The primary goal of the design engineering technology program is to "expose the student to challenging opportunities in mechanical design, including new materials, techniques, processes, etc., and thoroughly acquaint him with the current trends, ideology, and tools of technical and computer-generated graphics." The educational philosophy that supports that goal is that "students must have a foundation in theory, **coupled with viable applications experience**, before education becomes truly meaningful." That philosophy, shared by the other sections of the technology department, sets the technology curricula apart from traditional engineering curricula and results in an instructional program in which fully half of the student's work is practical, "hands-on" experimentation and application.

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*According to the design technology faculty, many companies had been forced to employ graduate engineers to fill design positions because of industry's growing need for qualified technical personnel. The design faculty viewed this process as "counterproductive in view of the engineers' sophisticated training and interests" and developed the design technology program to produce graduate designers specifically trained to meet the industrial need.

**AIDD is a professional group organized to advance the state of the art in the industrial drafting and design community. The institute has an educational arm which certifies high school, technician-level (2-year), and baccalaureate (4-year) design programs.

Among the technical objectives of the design program are the following: 1) to familiarize the student with basic problems in design development, including documentation and production techniques, precision dimensioning and tolerancing (among these techniques are computer-assisted design, parametric design, and automation within the design cycle); 2) to teach basic computer-aided design, manufacturing, and engineering (CAD, CAM, CAE) principles; 3) to assist the student in becoming knowledgeable about the proper use of modern production tools, machines, and equipment; 4) to aid the student in learning the basic manufacturing processes and how to achieve economical production by selecting the proper process; 5) to acquaint students with numerical control systems and their applications; and 6) to provide students with opportunities to participate in actual industry-related design problems.

Facilities and Equipment.—At present, the engineering sciences and technology building houses four instructional laboratories containing interactive graphics and computer-aided design equipment. One of these laboratories, called "The Apple Lab," contains a total of 25 microcomputers (including 8 Apples) that are programed to simulate many of the basic computer graphics functions of Computervision or Applicon systems. The Apple Lab is used to train freshmen in the technology and engineering departments in the basics of computer graphics. Students in more advanced classes use sophisticated industrial equipment located in the other instructional laboratories. That equipment includes two Applicon 885 multiworkstation IMAGE configured systems (eight workstations); a Computervision CADDS three multiterminal system; a Computervision CADDS four multiworkstation system; a Calma DDM system, also multiterminal; and a Tektronix 4054 system used principally by electronics students.

Curriculum.—In contrast to the manufacturing technology curriculum—which stresses conventional manufacturing skills and knowledge in the beginning of the programs and moves gradually into computer-oriented processes on the senior and graduate levels—the design curriculum focuses on computer-aided techniques and applications from the outset.* All design students study seven principal areas—graphic science standards, problem analysis, planning, design synthesis, evaluation, documentation, and application—all supplemented by the computer systems in the school laboratories.

The design program builds on the basic design and drafting skills and knowledge developed in the required freshman and sophomore courses covering the fundamentals of engineering graphics, mechanical drafting (which includes automated drafting techniques), and principles of descriptive geometry. While computer-aided techniques are taught as part of individual lower-division courses, half of the required courses for juniors and seniors focus entirely on computer graphics and computer-aided design. Two of the six design courses required during the junior year, for example, are: 1) "Professional Graphics Applications—Interactive Computer Graphics," and 2) "Computer-Aided Design—Interactive Graphics 1."

- *Professional graphics applications* reviews the development of computer graphics; covers the fundamental terminology, concepts, and principles of computer graphics; introduces the students to the uses and applications of 2- and 3-dimensional systems; and teaches operational techniques. Students in this course study the capabilities and functions of Apple, Applicon, and Computervision systems and complete laboratory work focusing on operational techniques required by each system.
- *Computer-aided design—interactive graphics 1* provides students with exposure to a broad range of engineering applications that can be executed on CAD systems; trains them to execute vendor-prepared applications packages dealing with engineering problems, and exposes them to CAD software development. Among the applications and techniques studied in this course are finite element modeling, digitizing, parametric programing, numerical control part programing, and detailing 3-D drawings.

In their senior year, students are required to take two other computer-oriented courses:

- *Basic computer-assisted part programing* provides students with a practical working knowledge of APT programing techniques; gives them a frame of reference to help them to understand and implement computer-aided design and manufacturing processes; and explores the impact of APT and automation in general on the traditional techniques and philosophy of engineering graphics.

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*This, according to design program faculty, reflects current practice in industry, where CAD techniques are more widespread than CAM techniques.

- *Design technology—CAD software development (interactive graphics 2)* explores CAD software development research techniques, programing, and operation of automated and computer graphic equipment with the object of acquainting students with CAD databases and database manipulation tools.*

In addition to the required courses, two graduate courses in advanced computer-aided design and advanced CAD applications are open to seniors as elective courses (see section on Graduate Programs).

Enrollment Trends.—The design technology program has the highest enrollment of the technology programs. In fact, with a 1982-83 academic year enrollment of 574 undergraduates, the design faculty is now in the position of having to introduce enrollment controls to eventually reduce the number of design students to 300. The primary reason for adopting this measure is to enable design students to spend a minimum of 5 hours a week working on the CAD stations. Approximately 30 of the design undergraduates are women, giving this program the highest percentage of female enrollment of all the technology programs.

A recent analysis of the enrollment figures (done when the enrollment totalled 555) revealed that 77 of the design students were freshmen; 119 were sophomores; 155 were juniors; and 204 were seniors. The relatively small number of freshmen and sophomores does not reflect an enrollment decline at the lower division level; rather, it reflects a general enrollment trend seen in all of the sections of the technology department of upper-division transfers from other disciplines.

Placement.—Like the other BYU technology programs, the design program has a placement rate approaching 99 percent. With only occasional exceptions, those who do not accept immediate employment in the design field go on to graduate school or into the military. One reason for the high placement rate is that the faculty actively encourages students to work in industry to get application experience before going on to graduate work. Most students receive two or more job offers, and program graduates have been employed in the following firms (to list but a few): Sandia Laboratories, General Electric, Texas Instruments, Boeing, Applicon, Garrett Corp., John Deere Product Engineering Center, Hughes Aircraft, General Dynamics, Signetics, U.S. Steel, Martin Marietta, Xerox Corp., Calma Co., Bechtel Power Corp., Westinghouse, Rocketdyne, and Motorola.

The majority of graduates are employed in engineering positions directly after graduation. Specific occupational titles assigned by the hiring companies include the following: design engineer, CAD applications engineer, process engineer, manufacturing engineer, CAD/CAM engineer, computer engineer, rocket design engineer, software engineer, product design engineer, associate engineer, and engineer. Others are employed as CAD/CAM programers, software analysts, tool designers, CAD support technologists, computer graphics specialists, and CAD/CAM consultants.

A number of graduates are hired as CAD or CAD/CAM managers or as management trainees, and a growing number are hired as CAD/CAM trainers. Another growing occupational opportunity for which design graduates are well prepared is technical marketing support—a number of recent design graduates have been hired as technical personnel who accompany equipment salespeople to answer the customer's technical questions and to help them make realistic appraisals of whether or not CAD and CAM equipment will perform desired functions in specific environments.

Graduate Programs.—In 1977, the technology department established an M.S. program in computer-aided manufacturing. Now retitled computer-integrated manufacturing (CIM), this program currently offers separate options in CAM and CAD and may in the future offer an option in computer-aided testing (CAT) for those students specializing in advanced electronics applications. The renaming of the CIM program not only made specific options in design and manufacturing available but also emphasized the thrust of the program, which is to provide students with training in the use of specific computer applications (e.g., robotics and group technology) as the basis for the study of integrated manufacturing where a variety of computer-aided equipment is linked in a distributed system.

One unusual feature of the CIM program is that over half of its students are professional engineers and managers employed by the Western Electric Co., who attend condensed, intensive versions of the regular school-year courses for 5 weeks each summer over a period of 5 years. The remainder of the students enrolled in CIM are full-time graduate students. At present, 30 full-time students and 60 Western Electric engineers are enrolled in the program. The first eight Western Electric students completed their coursework during the spring 1983 term.

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*Students are also required to take a noncredit "Design Technology Seminar" each semester. Seminars are held twice a month. Once each month the design technology students join with all students in the college to attend the Engineering College lecture covering a recent topic in engineering; the other monthly meeting addresses recent developments in computer-aided engineering and is specifically geared for design students.

In the fall of 1983, the technology department began to offer another graduate degree program in technical management. This new program offering is the result of a cooperative effort between the College of Engineering Sciences and the School of Management, and will combine MBA courses with technical electives from either the technology department or the traditional engineering departments. Students choosing to supplement management courses with technology coursework will pursue the technology management option, while students electing to take coursework from the engineering departments will follow the engineering management option.

Since the technology/engineering management program has not yet been offered, the remainder of this section will be devoted to the program in computer-integrated manufacturing.

Program Goals and Objectives: Computer Integrated Manufacturing.—The major goal of the CIM curriculum is to prepare graduates to integrate computerized systems in manufacturing environments, and to do so with a high degree of effectiveness. Specific objectives defined to support that goal are the following:

- to instruct students in the principles, elements, philosophy, and techniques of effective manufacturing system design;
- to aid students in developing the ability to integrate computerized systems to solve practical, recurring problems; and
- to provide guidance to students completing the M.S. thesis requirement, which involves an in-depth study of a social, economic, or technical aspect of computer-aided manufacturing systems.

Entrance Requirements.—The program is specifically designed for students with recent industrial experience who wish to develop specialized skills and knowledge in technical and managerial aspects of computer-aided manufacturing and design. Applicants must, therefore, have at least 1 year of relevant industrial experience.* Other entrance requirements include: 1) a bachelor's degree in engineering technology, or, with the consent of the department, a B.S. in an allied discipline such as engineering; 2) evidence of completed coursework in manufacturing processes, materials science, design and graphics, electronics, computer programing, physics, and calculus.

Faculty, Facilities, and Equipment.—Graduate courses are taught by approximately two-thirds of the technology faculty. Facilities and equipment are the same as those available to undergraduate technology majors.

Curricula.—Both CIM options are structured to accommodate industrial requirements and to prepare students for advanced work in computer-aided design and manufacturing. While students may create individually focused options within the two formal options (CAD and CAM), specified courses are required to form a foundation on which to base the individualized program.

CAM Option—Students choosing to specialize in computer-aided manufacturing take the following courses:

- *Computer-aided facility design and materials handling*—theory and application of plant layout techniques, emphasizing materials handling systems.
- *CNC part programing*—programing techniques and requirements for the manufacturing of components on computer numerical control machining centers, emphasizing programing, applications, and software development.
- *Group technology*—classification theory and practice applied to workpiece-classification-and-coding and statistics, production in manufacturing cells, design retrieval, and generative process planning (all with an emphasis on computer applications).
- *Computer-aided manufacturing systems*—basic activities, elements, and principles of computer-aided manufacturing, including terminology, systems integration, architecture, database development, interfaces, and computer hardware/software requirements.

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*The only exception to this requirement is that students who have completed a year of cooperative education experience (which, in actuality, is only 8 months of work experience) are eligible to apply. The technology faculty, however, actively encourages technology undergraduates contemplating this advanced degree to work full-time in industry before applying in order to gain a practical understanding of industrial practices before beginning graduate work.

- *Industrial robotics*—history and philosophy of robotics, industrial applications, programing, economic justification, and integration with production systems.

Students are also required to take a course in computer-aided design (see below) and a graduate seminar, and may choose from a number of senior- and graduate-level manufacturing, design, and electronics technology courses or courses in computer science, mechanical engineering, or business management to complete their option.

CAD Option.—Students taking the computer-aided design option are also required to take the manufacturing technology courses in group technology and computer-aided manufacturing systems. Two advanced CAD courses are also required:

- *Computer-aided design: interactive graphics 3*—CAD systems management philosophies, including systems evaluation, cost justification, procurement procedures, implementation, and management/operator training programs.
- *Advanced CAD applications*—philosophy, methods, and applications of engineering techniques pertaining to present and future trends of finite element and solids modeling; complex numerical control methods.

Elective coursework may be chosen from all three curricula of the technology department, the computer sciences department, and the mechanical engineering department.

Electronics Technology Coursework.—Although there is, at present, no formal electronics option in the CIM program, a number of upper-level and graduate courses that focus on computer-aided applications and techniques are available to students in the CIM program. Among these are computer-aided testing and instrumentation, electronics fabriction and assembly, and real-time sensing and control.*

Research.—All CIM students are required to do research and write a thesis, preferably on a practical aspect or application of computer-integrated manufacturing systems. In practice, areas of research have been very broad. A number of students participate in ongoing faculty research, while others initiate independent research projects in subjects such as selection of CAD equipment, CAD training, CAD system performance, computer-aided materials selection, carbide selection, finite element modeling, automated steel mills, solids modeling, software quality assessment, and the cost of product quality and its relation to market share.

The Western Electric Program.—In 1978, Brigham Young became one of a handful of universities participating in Western Electric's "On-Campus Summer Program," which provides selected Western Electric employees with the opportunity to attend graduate school on-campus for 4 to 5 weeks during the summer for a 5-year period. While the other participating universities—including Clemson University, Kansas State University, New Mexico State, Purdue, Texas Tech University, and the University of Illinois—offer a variety of advanced courses, some of which focus on CAD and CAM, Brigham Young is the only one to offer a degree program in computer-integrated manufacturing. Although Western Electric does not require the 60 employees currently attending BYU to enroll formally in the CIM degree program, almost all have chosen to do so. Those who formally enroll in the program must complete the same thesis requirement as all regular CIM graduate students, and all of the Western Electric employees receive the same classroom instruction and laboratory practice. Each summer, two courses from the CAM option are restructured to fit into an intensive 5-week period so that students complete the equivalent of two 14-week courses. The first eight graduates completed their studies in the summer of 1983, and two or three additional students were to complete their degrees by the end of the year.

Western Electric covers all of the students' formal costs— including fees, tuition, housing, and books—and also reimburses BYU for the salaries of the Technology faculty and staff, and for equipment use and maintenance.

Enrollment Trends, Attrition, and Placement.—While the number of Western Electric engineers officially enrolled in the CIM program has gone as high as 60, academic year enrollment is limited to 30. Of the 30 students currently enrolled in the academic year program, approximately two-thirds are graduates of BYU and over half are graduates of BYU technology programs. Many CIM students take leaves-of-absence from their companies to take the coursework, and attempt to complete the thesis requirement after returning to their jobs. This practice is the primary cause of attrition (approximately 33 percent), which often occurs after the coursework has been completed and when students return to work rather than remain on campus to write their theses. The placement rate for CIM graduates, on the other hand, is 100 percent. Average entry-level salaries received by CIM gradutes range from $27,000 to $33,000, although some program graduates have received offers as high as $50,000.

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*The "Real-Time Sensing and Control" course focuses on writing computer language for computer operations that run in real time (i.e., are not stored by the computer and computed in a batch mode).

Industrial Affiliations

The technology faculty operates on the philosophy that, in meeting the needs of industry it is meeting the needs of its students. The discussion in the preceding section has brought out a number of ways in which the faculty has sought industrial advice, secured industrial donations, and engaged in research that is either industry-oriented or conducted in cooperation with industry. The following paragraphs describe specific formal channels through which the technology department communicates with industry and discusses the department's position on the formation of an industrial advisory council.

Channels of Communication.—The technology department participated with the other departments in the college to form the **Alliance With Industry Program** in 1981. The 20 companies who participate in the program* each provide an annual contribution of $10,000 or more to support the college's research and educational programs. Benefits to the industrial partners include the following: 1) licenses for software developed by college faculty (including high-resolution graphics software developed by a member of the engineering faculty), 2) research results in methodology and applications, 3) help in solving special industrial problems, 4) seminars for technical personnel, and 5) access to BYU graduates skilled in computer-aided techniques. Benefits to the college, aside from donations of funds and equipment, include industrial advice and interaction and the opportunity to do research on current industrial problems.

Apart from its participation in the college-wide alliance with industry, the technology department has also formed independent alliances. Each year, the department holds two DCLASS conferences, one for users who have licensed the software and one for nonusers who are considering purchasing a license. The users conference provides a forum for the exchange of ideas and the presentation of new DCLASS applications; the non-users conference includes an initial orientation followed by demonstrations, workshops, and presentations by industrial representatives who use DCLASS and by technology department faculty.

The Manufacturing Consortium that supports the development of CAST holds twice-yearly meetings to review and approve the instructional modules as they are completed. The industrial members of the consortium also provide financial resources and technical information on the manufacturing processes which are the subject matter of the instructional packages, and the educational members write the software, participate in the review process, and help to evaluate the teaching/learning process employed.

The Western Electric program described earlier in this study gives the technology faculty an opportunity to work intensively with engineers and technical personnel, and faculty leave programs allow faculty members to renew their working knowledge of industrial practices by accepting short-term employment in industry. In addition, all faculty members take at least one trip a year to attend meetings of professional and technical societies. Another fruitful channel of communication is provided by industrial visitors. Literally thousands of industrial representatives visit the department each year—some to view the facilities and equipment, some to deliver or attend seminars, and many to ask advice on computer-aided equipment and methods.

Evaluation of Present and Future Capacity

When asked to evaluate BYU's technology programs on the basis of the skills and ability of their graduates, one employer replied: "On a scale of 1 to 10, I'd rate them 10." Other employers contacted agree, noting that BYU graduates not only have "just the right education," but often require less on-the-job orientation training than traditionally educated engineers, and are also more mature and more willing to work extra hours and at odd hours than most engineers fresh out of college.

The Rocky Road to Success.—Evaluated with respect to its own stated goal of preparing students for positions requiring applied engineering, process planning, and systems management skills, the BYU technology department clearly is highly successful. Its present capacity to provide its students with the CAD and CAM skills sought by increasing numbers of industrial firms is perhaps best described by the adage, "success breeds success." Because the faculty has been able to obtain industrial donations, state-of-the-art equipment, industrial advice, and real-world research problems for its students to work on, BYU technology graduates are sought after by industry. And because of the graduates' success in industry and the faculty's achievements in research, the technology department now has more offers of equipment and industrial research projects than it can handle and is in the position of giving advice to companies less technologically advanced than it is.

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*These include B. F. Goodrich, Boeing, Digital Equipment Corp., Evans & Sutherland, Garrett Corp., Hewlett Packard, Exxon, GE-Calma, Genrad, GTE, and Computervision.

A look at the history of the technology department since its inception in 1960, however, reveals that its present-day success story grew out of a Cinderella tale. When the baccalaureate programs were first established, and for many years afterwards, the members of the technology faculty saw themselves as "underdogs." They were looked down upon by many of the engineering faculty, and unrecognized by most of the rest of the university, and their 4-year programs were often confused with the 2-year technician programs also offered by the technology department at that time. Industry-oriented and intent on filling the gap created by the increasingly theoretical focus of traditional engineering education, the technology department resisted promptings by engineering societies, accreditation agencies, and some of the college faculty to "add more courses the students wouldn't need in industry in order to become accredited—it wasn't worth the tradeoff."

Eventually, the manufacturing and design programs—which substituted application-oriented, laboratory-based courses for the most highly theoretical coursework in engineering disciplines—became the first accredited technology programs in the country. Although accreditation was beneficial to both the students and the faculty, it did not solve their problem of being looked upon as either second-rate engineers or as supertechnicians. However, the department's industrial focus and the faculty members' desire to prove that neither they nor the discipline of technology were "poor relations" were significant factors in the department's early concentration on computer-aided design and manufacturing.

Because the programs were designed to teach state-of-the-art industrial skills and applications, the faculty began exploring ways of obtaining equipment and incorporating programmable automation into the curricula approximately 10 years ago, when it became clear to them that CAD and CAM would eventually become required fields of knowledge. Furthermore, because the programs' curricula were not bound by engineering accreditation requirements, which allow little space in a 4-year curriculum for the inclusion of new courses, coursework focusing on CAD and CAM could be incorporated into the technology curricula with relative ease.

The final hurdle for the technology department was industry itself. Faculty members went from company to company in the early 1970's, but did not succeed in obtaining donated or reduced-price equipment until they proved their genuine interest and capability by demonstrating to Applicon that their students were doing all that could be done to automate the drafting courses with the limited equipment at their disposal. It was at this stage, when the department received its first major donation (the Applicon CAD system) that Cinderella was allowed to try on the glass slipper. The other slipper—a $130,000 Kerney & Trecker CNC milling machine, which the company sold to the department for $50,000—was fitted shortly thereafter. These two significant equipment additions enabled the faculty to begin to incorporate sophisticated computer-aided techniques into the coursework; they also encouraged other firms to donate funds and equipment.

Technology and Engineering: Interdepartmental Relationships

Once it "proved itself," the situation of the technology department improved both inside and outside the university. Although perfect accord between engineering and technology faculty members is not always achieved even now, the vast majority of faculty members in the college view engineering and technology as partner-disciplines, both of which are necessary to provide the broad spectrum of education and training required to prepare graduates for engineering and engineering-related positions in industry. Civil, mechanical, and electrical engineering students are now required to take design technology courses, and many engineering students take courses from all three technology programs as technical electives.

Technology students were always required to take engineering courses relevant to their major program—and a third to a half as many physics, chemistry, and mathematics courses as engineering students. There has been limited discussion about increasing the number of statics, dynamics, and strength-of-materials courses taken by technology majors to equal those taken by engineers, and there is some discussion about increasing the numbers of physics and mathematics courses in the technology curricula.* As the commonality between technology and engineering curricula grows, more and more students and faculty perceive the difference between the two disciplines to be one of **approach** and **mission**, rather than one of level of education.

Computer-Aided Engineering, Design, and Manufacturing (CAEDM) Committee

Both technology and engineering faculty now feel that they have an excellent relationship with each other, in contrast to the situation in many other universities which have both programs. The CAEDM Committee, created in 1980, provides a formal channel of communication between the technologists and engineers, and a number of professors in both departments coordinate research projects in which technology and engineering graduate students work together as part of a research team. College faculty believe that this team approach has a great deal of significance for academia and industry alike.**

The BYU technology department—whose primary focus is on the **implementation** of engineering designs—has been instrumental in increasing the engineering departments' awareness of the need to produce industrial designers who are more cognizant of manufacturing concepts and requirements. One tangible example of interdepartmental cooperation in this area is a CAEDM-sponsored short-course for faculty and students delivered by a representative from GE, which has instituted a version of a Japanese procedure that rates engineering designs on the basis of ease and efficiency of assembly. Another example is the work now being done in the CAM Mini-Lab, where electrical and mechanical engineering students, computer science students, and technology students all participate in projects addressing the manufacturing process from design to production and the problems of networking diverse CAD and CAM equipment.

The technology department also stimulated the engineering departments' interest in CAD and CAM, which, in turn, was a stimulus for the current focus on computer-aided engineering (CAE). The college as a whole has also benefited from the industry interest generated by the technology programs and graduates. Much of the computer-aided equipment obtained by the technology department serves the entire college, and the engineering departments have now obtained computer graphics and computer-aided data acquisition and analysis equipment through industrial donations and cooperative agreements with equipment manufacturers. In addition, the growing reputation of the technology department in industrial circles has brought in interviewers from across the country who hire engineering as well as technology graduates.

The Alliance With Industry Program, formed under the auspices of CAEDM, brought the university $1,858,000 in industrial equipment and in funds used to augment the computer-aided capabilities of the college. In April 1983, CAEDM hosted a conference for 380 representatives from 120 universities across the country who are either planning or developing programs in computer-aided manufacturing, design, and engineering. Thirty speakers from 25 universities that have initiated such programs gave presentations on the approach taken at their respective institutions; and all of the participants had the opportunity to discuss common problems, individual experiences, and appropiate strategies. The object of the conference, called University Programs for Computer-Aided Engineering, Design and Manufacturing (UP CAEDM) was to increase communication among universities and to provide impetus for the implementation of teaching and research programs in CAD, CAM, and CAE.

Problems.—While cooperative endeavors like those mentioned above have brought the faculty of the technology and engineering departments together, the college is not entirely free of the traditional misunderstanding among engineers and technologists. Some of the technology faculty still bear the scars of old battle wounds and refer to the "arrogance" of the engineering discipline as a whole, and to the "old boys' club" atmosphere that links engineers nationwide and excludes technologists. They consider their own college education in traditional engineering schools to have "mistrained" them for industrial occupations. Some engineering faculty, on the other hand, resent the fact that most technology department graduates are classified as "engineers" when they move into industry; they fear that such graduates may be "misrepresented" as degreed engineers. Another problem for the engineering faculty is that a number of visitors from industry and academia overlook the computer-aided engineering facilities and devote their entire attention to the CAD and CAM facilities of the technology department. The resentments on both sides are, however, gradually being overcome by the spirit of cooperation that now exists within the college. They are but pale reflections of national tensions between technologists and engineers.

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*There is some disagreement among the technology faculty on the issue of increasing the math and physics courses, which would entail either extending the technology curricula beyond the limits of 4-year programs, requiring students to take more courses each semester, or dropping courses that the majority of the faculty consider to be essential for technologists.

**A perennial problem in industry has been lack of communication between engineers who design the products and the manufacturing departments responsible for production. Because of this lack of communication, and because engineers normally receive little formal education in the requirements of the manufacturing process, industrial designers often fail to take manufacturing requirements into account when designing a product—a procedure that can lead to loss of money, loss of production time, or (in the worst instance) a product which cannot be manufactured.

Working With Industry.—Having designed its programs to respond to industrial needs and having concentrated on industrially oriented research, the technology department is now able to work with industry on many levels. The continuing success of the Western Electric program and the satisfaction of the Western Electric employees who attend the summer sessions indicate the suitability of the technology curricula to current industrial needs, as do the multiple job offers received by technology graduates. The growing number of companies purchasing DCLASS licenses and exhibiting interest in the CAST system indicate that the research performed by technology department faculty and students also fills an industrial need. Some faculty members, in fact, are in the position of being able to pick and choose from a large number of potential industrial research projects.

Because of the similarity of interest between technology department faculty and professionals in industry, and because of past success in research aimed at solving current industrial problems, individual faculty members have been able to engage in long-term research projects resulting in a number of shorter-term benefits to industry. DCLASS, for example, is now put to use by a number of firms for classifying and retrieving information and for generating process plans, time standards, and a number of other applications. At the same time, the creator of DCLASS is conducting long-term research into the potential use of DCLASS as a systems integration tool.

Revenues from the sale of DCLASS licenses have helped to buy equipment and renovate facilities and may soon be augmented by the sale of CAST training modules and the CAD training aides that allow Apple computers to simulate interactive graphics systems. In many instances, the department has been able to save the expense of maintaining computer- aided equipment by writing software programs for equipment vendors in exchange for maintenance services.

The major problem-area still remaining for the technology department in respect to working with industry is the attitude taken by some firms toward the occupational categories appropriate for technology graduates. This is discussed in the following section.

Future Capacity.—Judged by its present success, the direction of the faculty's research, and its determination to maintain its awareness of industrial needs and techniques, the future potential of the technology department to continue producing well-trained graduates versed in computer-aided techniques and familiar with a wide range of computer-aided equipment seems high indeed. The major limitation is the small size of the department—which, because of enrollment control, will become smaller still—and difficulties encountered in managing the growing numbers of computer-aided systems, which entail coordinating frequent upgrades and updates with the student need for equipment time.

Although college and university administrations have been generous in assigning funds to upgrade old facilities and build new ones for the technology and engineering departments, the technology department's resources cannot expand to accommodate all of the activities it would like to engage in. For example, a number of companies have requested that the department operate programs for their employees on the model of the Western Electric program. The department has had to turn down these requests for lack of resources. It will, however, attempt to offer a series of 2-day to 1-week seminars for industrial employees focusing on computer-aided design and manufacturing.

A general policy of the department and of the university is to sacrifice size for quality. The new enrollment control procedures, for example, will effectively close off enrollment for the Design Program for the next year or two, but will also result in more CAD-terminal-time for those students already enrolled. Of the three technology programs, manufacturing exhibits the greatest capacity for future enrollment growth (student interest has been fueled by the national interest in productivity and the potential of computer-aided manufacturing), while the electronics program has the greatest potential for expanding its curriculum to include new courses focusing on computer-aided equipment and techniques. The Electronics faculty has already acquired six HP87XM computer-aided test stations to be used as personal instrument systems, and a Tektronic 4054 computer graphics system for printed circuit board design.

Future departmental plans call for an ECAM (Electronics-CAM) minilab to be established in the new technology building when it is completed.

The technology department, in cooperation with the mechanical engineering department and the electrical engineering department, developed a proposal for a three-element graduate program in manufacturing systems in response to IBM's announcement that it would provide college and university grants for the development of new curricula in manufacturing techniques. BYU has received notice that it has been awarded an IBM 4341 computer system with 10 CADAM graphics terminals. This system will have a significant impact on the capacity of the three departments and of the college as a whole to train more students than they can presently accommodate.

The technology department's potential capacity to provide education in programmable automation is not entirely limited by the size of the department, if one considers the indirect impact of the programs as models for other schools, the willingness and ability of the faculty to provide information to academia and industry alike, and the potential of the computer-aided simulation training packages and the CAM-Mini Lab concept.

BYU Technology Programs as Models for Other Educational Institutions.—The manufacturing technology program has been used for many years by the Society of Manufacturing Engineers as a recommended model for 4-year manufacturing programs. In addition, representatives of 15 to 20 colleges and universities visit the BYU technology department each year with the expressed intention of creating their own programs on the BYU model.

Technology department faculty representatives offer the following comments on the feasibility of such attempts. While they have personal knowledge of a number of successful programs modeled on their own, they point out that the crucial requirements for a program like theirs are often met only with difficulty. The first requirement, from their point of view, is the necessity of "giving up the title of manufacturing engineering in order to give industry what it really wants." This is a step that a number of engineering schools do not wish to take.*

Once this step is decided upon, other pitfalls exist. One is the tendency of some schools to place manufacturing technology programs in the department of mechanical engineering and to offer them as options. The danger here, according to BYU faculty, is that the technology program is then likely to become a watered-down engineering program rather than a parallel-track program. Another necessity is that each course in the curriculum be accompanied by an associated laboratory requirement. This means, of course, that appropriate equipment and facilities be available. Another major requirement is that the faculty have industrial experience and be comfortable teaching a less theoretical, practically oriented curriculum. The final requirement is interest on the students' part. While faculty can help to generate that interest, it could be difficult to do so in a strong traditional engineering college where students are bent on becoming degreed engineers and have little interest in less theoretical studies.

Technology Transfer.—The technology department—and, especially since the formation of CAEDM, the college as a whole—has been, and will most likely continue to be, an excellent conduit for technology transfer. The faculty demonstrates a strong determinaton to continue to learn from industry and an equally strong desire to share what they have learned and their methodology of teaching with other educational institutions. The UP CAEDM conference, in particular, has the potential of becoming a regularly occurring event: the second such conference is being hosted on the East Coast by Lehigh University in 1984. If that potential is realized, BYU will have provided the impetus for a sorely needed forum for continual exchange of information.*

Technology department faculty also express the intention of continuing the present practice of working as consultants to industrial firms and government agencies and of providing informal advice and services to industry representatives who visit the department to obtain information on CAD/CAM systems and applications. Thus, the technology transfer provided by the technology department and other departments in the college is likely to continue to operate on multiple levels to the benefit of BYU, other academic institutions, and industry.

Computer-Based and Computer-Aided Instructional Packages.—As modules of the Computer-

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*According to one technology instructor, "You can't take a true-blue theoretical engineer and expect him to teach technology; if you do, there's a danger that the faculty will make the technology courses too theoretical and the students will wind up with a pseudo-technology degree."

*An informal survey conducted by this researcher of selected colleges and universities revealed an astonishing lack of knowledge about the activities of other institutions on the part of faculty members actively engaged in planning or developing CAD and CAM programs. While some faculty members contacted did have some information about existing programs in colleges and universities, they often did not know the direction and focus of those other programs or had inadequate information about specific research and curriculum development activities.

Aided Simulation Training System (CAST) are completed and approved by the Manufacturing Consortium, they will be made available to industries and educational institutions for a minimal fee (covering the cost of reproduction and mailing). The manufacturing technology professor responsible for developing and coordinating the project is hopeful that within the next year, videodisk technology in the United States will be well enough advanced to allow the CAST development team to produce the training modules on interactive videodisks. At present, a demonstration videodisk has been produced for use in further research studies on interactive instruction, and sound-slide presentations of some of the modules are being tested in manufacturing technology classes at BYU. The CAD training package for use on Apple computers is also in the development stage, and one of the design technology faculty has formulated a concept for computer-aided CAD instruction which he hopes to develop in the near future.

CAM Mini Lab.—Technology department faculty are also seeking funds to enable them to build duplicates of the miniature factory that will be contained in the CAM Mini Lab and to provide them to 20 universities across the country. The recipient universities would be encouraged to attend "software exchanges," whereby advances made by one party would benefit the group as a whole. The estimated cost of producing the hardware for one minilab is $50,000, which is equal to or less than the cost of many single items of computer-aided equipment.

Projects such as those mentioned above expand considerably the department's potential capacity to have a direct effect on education and training in the field of programmable automation. The DCLASS users and nonusers conferences, the Western Electric program, and short courses for professional engineers offered by the engineering departments further expand the college's ability to reach beyond the university campus to provide educational opportunities to working professionals.

Case Study 3
CADAM Inc.: Customer Training in Computer-Aided Design

Summary

CADAM Inc., a subsidiary of Lockheed Corp., produces computer-aided design and manufacturing (CAD/CAM) software, most of which is licensed to customers through IBM and other computer hardware firms. Customers may also buy CAD/CAM software directly from CADAM for use on systems that are "plug-compatible" with IBM systems.

CADAM provides basic computer graphics training free of charge to all customers who purchase software directly from the firm (two employees per customer) and charges $1,250 per student for basic training classes to all customers who license the software through IBM or other hardware distributors. Customers may also purchase the basic training in self-study packages for $650 per kit. The software firm offers more than 11 computer graphics programs, ranging from basic training in the CADAM system of computer-aided design, to courses on 3-D piping and 3-D surfaces, to numerical control (NC) programing, to finite element modeling.

In addition, CADAM offers a training consulting service designed to assist customers who have unique problems or special requirements. All training beyond CADAM basic is delivered for a fee, which ranges from $550 to $3,100 per student, depending on the length and complexity of the course. The majority of students are machinists, designers, drafters, and engineers.

While CADAM provides both in-plant training for all of its employees and what is referred to as "scope" training (training on the computer terminal in the operations required to use various CADAM® system ware packages),* this study will focus primarily on the customer training offered by the firm. When it was established in January 1982, its Lockheed Corp. founders committed themselves to providing "high quality training" which they saw as crucial to support the company goal of becoming a major developer and distributor of software in the CAD/CAM field. Today, the training department—which includes curriculum designers, internal trainers, and customer trainers—accounts for 8 percent of all CADAM employees (an unusually high percentage), and the director of training reports directly to the president of the firm. This, again, is unusual, since most training departments report through marketing, customer relations, or personnel.

Company Characteristics.—As of July 1983, CADAM employed approximately 280 people in its four major divisions: software development, marketing, training, and administration. Seventy-five percent of CADAM employees are in the software division; marketing and training have 10 percent each; and the remaining 5 percent are in administration. At present, the firm operates out of one facility, located near the Lockheed-California plant in Burbank, Calif. CADAM management plans to increase the software division by 40 employees during the latter part of 1983 and to maintain the training department at its current level.

The decision to incorporate what was once Lockheed's CADAM division* was fueled by the perceived necessity of providing CADAM management with the flexibility it needed to operate in a fast-moving CAD/CAM marketplace with a wide variety of potential customers in aerospace, shipbuilding, automaking, architectural planning, and a number of other industries. Distinguishing CADAM from the majority of CAD software and software-hardware houses is the firm's concentration on developing software for mainframe CAD/CAM systems, specifically the IBM 370, 303X, and 4300 series, rather than for turnkey, or stand-alone, systems utilizing minicomputers.

According to company representatives, the advantages of mainframe as opposed to turnkey systems are increased database capability and the ability to network CAD/CAM databases (including the ability to transfer data between CAD and CAM systems), the ability to interface to other information systems, the greater growth capability of mainframes (to which over 100 terminals can be connected), greater telecommunications capabilities between far-flung terminals, and the increased speed, accuracy, and computing ability offered by 32-bit (mainframe) as opposed to 16-bit (minicomputer) systems.* By offering these features, CADAM believes it has a solution for an entire enterprise—not merely a department or group.

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*CADAM is a registered trademark and service mark of CADAM Inc.

*In 1967, the original CADAM software was developed by Lockheed-California engineers to aid in the numerical control (NC) programing and airframe design for Lockheed Aerospace Products. CADAM system software was originally created for use on IBM mainframes, but by the mid-1970's, Lockheed had also designed a CADAM package for use on Perkin Elmer minicomputers. By 1975, Lockheed was selling CADAM system software to users outside of Lockheed Corp. By 1979, in addition to marketing the system, IBM also adopted CADAM as its internal CAD/CAM software. IBM and Lockheed entered into a contractual arrangement in 1977 whereby IBM would market and distribute CADAM system software under the IBM installed user program (IUP), which makes software developed by IBM users available to the general public.

According to CADAM's president, CAD/CAM technology is most profitably and productively used by firms that are not merely seeking to automate single processes, such as design drawings or NC part programing, but are instead developing the capability to make their design and manufacturing processes into a single integrated system. CADAM management thus views the firm's major role as that of a systems catalyst, since they maintain that CAD/CAM systems can, when used by knowledgeable users, become the backbone of a computer-integrated manufacturing (CIM) system. In this sense, CADAM has two major markets: firms that use CAD or CAD/CAM systems for some processes, and, most important, firms that are in the process of developing integrated system capabilities. At present, CADAM has over 250 corporate users, including IBM (with almost 100 installations and several hundred terminals that make use of CADAM software), GM and other American firms, the majority of the largest Japanese automakers and shipbuilders, and firms throughout Western Europe, Canada, South Africa, and South America.

Training Organization and Philosophy.—Lockheed-California began CADAM system training for employees in the late 1960's, shortly after the CADAM product was developed; Lockheed instructors have been delivering CADAM system training since 1975, when software packages were first sold to outside users. As a company, then, CADAM had the advantage of starting out with a track record of training both customers and employees on a system that had been used in production environments for over 15 years; it also inherited 10 Lockheed-developed CADAM training programs and a number of experienced trainers.

Top Priority Accorded to Training.—According to CADAM's president, training was an integral part of the strategic business plan created prior to CADAM's incorporation. Convinced that customer support—including training, curricular aids, and consulting services—was a major requirement for success in the CAD/CAM field, CADAM management set out to establish a training department that would provide curricular materials and training of a consistently high quality. The new director of training and education, hired in November 1981, was given a mandate to produce quality training and to turn the training department into a profit center for the firm. As head of one of CADAM's four major divisions, the director of training reports directly to the president of the firm and has both **flexibility** (in structuring the training department, hiring trainers and program designers, and organizing and developing the training material) and **accountability** (for producing "quality product support" and for turning a profit).

CADAM management believes that a system of checks and balances—involving cooperation between trainers and designers and between the software division and the training division, as well as accountability on the part of each division to the others and to top management—produces a form of "quality assurance" whereby the product itself is designed with users and training requirements in mind, and the training effort supports the sale and use of the software.

Relationships With Educational Institutions.—Aside from the training division's informal relationship with the University of Southern California's (USC's) Instructional Technology Department, CADAM has numerous cooperative relationships with colleges and universities in California and throughout the country. In September 1982, IBM announced its intention to award $40 million worth of grants of hardware and of funds to university and college engineering schools to develop new curricula in manufacturing techniques. CADAM intends to supplement the IBM hardware donations with donations of software licenses.

Independently of the IBM grant, CADAM donates software to a number of universities and colleges, to be used in teaching CAD/CAM fundamentals, and occasionally provides CADAM training to selected colleges and universities for free or for

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*Many of the major turnkey vendors, however, are coming out with 32-bit minicomputers, which, according to Merrill Lynch's 1982 *CAD/CAM Review and Outlook*, "appear capable of stemming the inroads of mainframe computer competition" (p. 1). While mainframes have more CPU power and speed, the new 32-bit mini systems offer more extensive applications software and, except for "high-end large sophisticated needs," are superior to mainframes in price/performance comparisons (p. 9).

a reduced rate. A more active relationship exists with a smaller number of schools to which CADAM also provides test releases of software. This arrangement gives students experience in solving software problems while, at the same time, aiding CADAM software analysts in debugging the software. With yet other institutions—UCLA and Rensselaer Polytechnic Institute for example—CADAM has engaged in joint development work. UCLA's Department of Manufacturing Engineering has received grants of IBM hardware and CADAM software, which it has integrated into the curriculum of three separate courses. CADAM and UCLA manufacturing engineering faculty and graduate students are also engaged in joint research to determine how to classify CADAM-made drawings into part families by using group technology codes, with the ultimate object of developing an integrated manufacturing planning system.

Another cooperative project conducted by UCLA aims to narrow the traditional communications gap between the design and manufacturing departments in industries by designing a "smart" CAD system that will monitor the design process and prompt the designer if he bypasses manufacturing considerations while designing a part, tool, or product. Another UCLA-CADAM project involves research into incorporating three-dimensional graphics capabilities into CADAM system software.

Other educational institutions with which CADAM maintains a close working relationship include Rensselaer Polytechnic Institute, Michigan Technological Institute, MIT, and California Polytechnic State University. Section III of this study discusses possible future projects with colleges and universities which may have a direct impact on CADAM system training itself and on the educational offerings of participating schools.

Training Division Staff.—The training division consists of the director of training, the internal training group, the customer training group, the program (i.e., curriculum) designers, and three support personnel.

The training director, who was in computer sales for IBM from 1956 to 1969 and then moved into the industrial training field as an early employee of Tratech (a for-profit training firm) and a training consultant, combines experience in the computer and training fields with formal training as an accountant. The remainder of the professional staff in the training division is approximately equally split between employees with advanced degrees in instructional design, education, or the sciences, and employees with practical experience working on and teaching the CADAM system.

The manager of customer training is a long-time Lockheed employee (previously a drafter/designer) who was trained as a drafting designer on CADAM when it was first put into use in the late 1960's. A trainer in the CADAM system since the early 1970's, he became manager of customer training shortly after moving to CADAM from the Lockheed training department. Five of the six trainers combine production experience as CADAM system designers with experience as CADAM system trainers for Lockheed. The senior instructor has 20 years of training experience, 15 of which were spent training Lockheed employees and customers on the CADAM system.

The manager of the program design staff has completed advanced graduate work in the USC instructional technology department and worked previously as a manager for another firm. The four program designers also have graduate and/or teaching experience in instructional technology at USC (one was an instructor, one an assistant professor), and one also has 10 years of industrial experience. All have had extensive experience in writing instructional curricula.

The difference in backgrounds between the trainers and the program designers reflects CADAM management's position that CADAM employees should specialize in what they do best—that trainers should be practitioners with engineering or shopfloor experience and that curriculum developers should be trained communication specialists. The horizontal nature of CADAM's internal organization—whereby trainers, program designers, and software developers are on parallel organizational levels—is intended to encourage cooperation and to make all technical-level employees accountable for portions of product development and support.

Training Facilities.—Approximately half of all the customer training is delivered at CADAM's training facility, located at the CADAM plant and also used for employee* Group II mainframe computer, which is shared with the marketing group.

Customer Training

Goals.—Major goals of CADAM customer training are to provide a high level of training support to the customers and to do so on a profitable basis.

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*The remainder of the training is delivered onsite at the customer's location.

Recognizing that the CADAM system cannot be effectively utilized by customers who have not been properly trained and that well-trained users are those most likely to be satisfied with the system and to expand their use of it, the training director established the program design department to support these goals with its own particular set of objectives.

These objectives are to develop a complete set of training tools for each customer training program, to make those tools (written curricula, study guides, training guides, training aids, etc.) as consistent as possible both in content and delivery, to package appropriate courses as self-study programs to reduce training costs, and to develop new instructional programs to keep pace with software development and new software applications. The trainers' goals are to make sure that the students have a basic understanding of how the CADAM system operates and a specific understanding of the particular application package they are being trained to operate.

Contractual Arrangements With Customers.—When CADAM sells or leases software licenses directly to end-user customers, free basic terminal operation training is provided for two customer employees. Intermediate terminal operation training and other CADAM training courses are then available to these customers for a fee.

Direct licensing makes up the smallest portion of CADAM sales. By far the largest distribution is through IBM, with which CADAM has three separate contracts: one for software licensing, one for software development and enhancement, and one for training. Under current contracts, IBM markets both CADAM system software and CADAM system training, and primary responsibility for provision of training and other support rest with IBM, which contracts with CADAM for actual training delivery. Responsibility for scheduling customers into training classes is also IBM's: CADAM provides IBM with a projected 6-month schedule of training courses, and IBM schedules customers into available classes. The contractual relationship with Perkin Elmer and Fujitsu are somewhat different than with IBM.

Program Design.—The principles of "instructional design"* will eventually be used in all of CADAM's training programs. At present, two courses have been fully revised by the program designers: 1) CADAM basic, and 2) 3-D piping, a new course designed for a software application program for the construction of pipe runs and spool diagrams. Four additional courses —basic II, analysis, CADAM implementation, and CADAM installation—were to be ready by the third quarter of 1983. As applied by CADAM designers, instructional design provides a systematic approach to defining, developing, and evaluating training programs—an approach which attempts to combine flexibility with an organized structure. The instructional design system is usable both for creating new programs and for revising old training material.

The instructional design system used by CADAM designers is a nine-part process which, in the case of the revision of CADAM basic training, took approximately 9 months to complete. The process is broken down into three major functions: 1) definition of the problem or situation, 2) development, and 3) evaluation.

Customer Training Programs.*—CADAM offers a total of 11 customer training programs plus a training consulting service. This section describes the basic terminal operations course.

Basic Terminal Operations.—CADAM's basic training program is offered approximately twice a month. Previously a 4-day course serving four students per class, CADAM Basic is now a 5-day course which can accommodate four to eight students and can be taught by CADAM instructors or trainers from customer firms, or can be used as a self-study package. When delivered by CADAM trainers, the basic course is priced at $1,250 per student; when sold as a self-study package, the cost is $650 per study kit with additional workbooks priced at $70 to $150 each.

Course Goals.—The major goals are to teach students to use the basic functions of the CADAM system to create engineering drawings and to understand the basic concepts and purposes of the system as applied to their own professional needs and work environments.

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*"Instructional Technology" or "Instructional Design" was originally developed in the late 1940's and early 1950's as a means of systematizing training and educational programs. It incorporates psychology, sociology, adult education, and other disciplines to create instructional programs that take into account such factors as audience makeup, level of learning, educational levels and occupational background of the students, and their responses to the type of training or education provided (e.g., responses to learning to work on computers). A consortium of universities (including USC, Michigan State, Syracuse University, the University of Indiana, and Florida State) have developed fully fledged graduate programs in Instructional Technology (IT).

*CADAM Inc. training programs not described in the preceding pages are the following: advanced numerical control programing, 3-D surface, 3-D piping, finite element modeling, and analysis procedures, management overview basic II terminal operations, job planning/on-the-job training, *basic* numerical control programing, and instructor training.

Prerequisites/Occupations Served.—The single prerequisite for the course is the ability to read blueprints. Most students who have attended the course have been drafters, designers, engineers, NC part programers, and managers of departments in which the system is installed. Originally used by industrial designers, the CADAM system is now also used by architectural designers, facilities planners engaged in floor and shelf layouts for markets, hospital supply houses and other firms, and by electricians and electrical designers who use the software for the design of printed circuit boards and wiring diagrams. Occupational categories of students enrolling in CADAM's basic course are thus becoming more diverse as the applications of the system multiply, and there are plans to adjust the basic course to reflect the changing audience.

Curriculum.—The course consists of eight lessons, each of which builds the students' ability to operate the CADAM system by introducing them to the use of one or more of the system's function keys. By use of the function keys, the operator calls up programs that enable him to create basic geometric shapes, to "edit" the geometry of his drawing—the "relimit" function key, for example, is used to trim or extend geometric elements—to indicate dimensions and to add notations, and to perform a variety of other operations. By the end of the course, the students will have learned the use of all of the function keys required for basic engineering drawings and will, in the process, have completed a series of practical exercises that result in a completed design of an industrial robot arm.

Lesson one begins with a general introduction, including a brief history of the CADAM system, its benefits, and the needs that it can fill; an introduction to the workstation (including a hardware demonstration); and an overview of the general operation of the system. Following the introductory lecture/demonstration, the students complete an audio-tape-guided introductory lesson on the graphics teminal, in which they learn how to enter and exit the system ("logon" and "logoff") and to perform a few simple operations. They learn, for example, to perform the basic file manipulation required to start a new drawing, call an existing drawing to the screen, and file a drawing on the computer disk.

From lesson two onward, the students spend approximately 70 percent of their time working on the terminals and learning the system by means of practical exercises. In lesson two, they learn how to use the circle, line, and point function keys to create points, lines, and circles at specific locations; to use the offset key to create a line in a desired direction, for example, or to create a new concentric circle; and to perform procedures for moving, sizing, setting, and presetting the display on the screen by use of the "window" function key, which can focus in on a small section of a drawing or can widen its focus to present a full drawing on the screen (like a camera taking either closeups or distance shots).

In subsequent lessons, the students learn to edit the basic geometry they have created (to create corners, to trim or extend elements, and to change the representation of an element from one line-type to another); to capture one or more elements for manipulation as a single entity or group, to analyze existing elements (e.g., lengths of lines, radii of circles, and relative distance between a pair of elements); to create textual notes and symbols to accompany the drawing on the screen; to create auxiliary views; to plot hard copies of the drawing; and to perform other basic functions.

In the final lesson, the students also learn job planning techniques and how to create and use a standard library of drawings.*

*Instructional Methods.*** The basic course is approximately 10 percent lecture (if delivered by an instructor), 20 percent in-class reading, and 70 percent practical experience on the terminal.

When used as a self-study course, the student workbook provides course content information and guides the student to consult the procedures guide which comes with the training package to help him/her complete exercises on the computer terminal. CADAM also provides instructions to managers to help them monitor the instruction and strongly recommends that, even when the course is delivered in the self-study mode, an experienced CADAM system user be on hand to answer questions and provide other assistance.

When used in a group learning environment, the workbook provides structure and support for the learning process, but the trainer becomes the primary resource by lecturing on course material, giving guidance to the students, and pacing the course to the students' speed.

The three critical elements in the instructional method—stressed by the trainers and in the workbook itself—are reading, planning, and careful performance of the exercises. The instructors encourage the students to read for conceptual understanding and to underline especially important sections. Planning is also an integral part of the instructional methodology. Each exercise is accompanied by a planning sheet for the students to complete. Once they read about the skills required to perform specific operations, they reinforce their understanding by planning how they will utilize those skills to complete the practical exercise. They then develop the skills by performing the exercise specified in the workbook.

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*A standard library is a collection of drawings of standard parts or models used frequently by a specific firm. Once the original drawings are completed by the firm's designers, they are stored in the CADAM library file and can be called up and used (as is, or modified).

**This section is adapted from the CADAM Manager's Guide.

Since each lesson is constructed of interlocking steps—each of which presents new information and introduces new skills while reinforcing skills and information learned in previous steps—students are strongly encouraged not to skip over any of the reading or planning phases.*

Training Materials.—Each student receives a workbook, a *Training Handbook and Procedures Guide,* a magnetic tape which is fed into the computer and contains student exercises, and audio tapes for the audio-guided segment in lesson one. In addition to the student material, the customer firm also receives a manager's guide.

Evaluation of Students.—Each lesson of CADAM basic contains a self-evaluation quiz to help students gage their own progress in the course. Successful completion of the training does not depend on passing a final examination, but employers sometimes request the trainers to provide them with informal evaluations of the students to help them determine which should be given chief responsibility for operating the system at the customer's site.

Student Evaluation of the Course.—Students are asked to complete written evaluations of the course, the instructor, and the training materials. On a seven-point scale, students rate the course objectives, handouts, visual aids, homework, course content, applicability to their own needs, and the instructor. They also provide comments on the usefulness of the material, and their own ease or difficulty in absorbing it, and suggestions for improvement. After the interim revision of the course, ratings improved by up to two points, jumping from five or below to over six on the seven-point scale.**

Follow-up.—At the present time, follow-up of program graduates is informal.* CADAM maintains a hot line which can be used by customers who experience software difficulties or run into operation problems they cannot solve, and a number of customers call the trainers directly for help with difficult problems.

Results

Number Trained.—From January through September 1982, CADAM instructors trained over 700 customer employees. That number, however, represents a small portion of trained CADAM system users, according to CADAM's training director. Because of the significant investment of time and money involved in sending employees to the CADAM training facility or bringing a CADAM trainer to the customer site, most users send an "advance guard" who receive the training and return to train other employees.

Productivity Results.—While it is difficult to obtain quantifiable data on the results of the training as discrete from the results of system use, the subjective evaluations of CADAM customers and the improvement in the student ratings of the basic course on CADAM's own seven-point rating scale indicate that, for the most part, CADAM system training effectively supports the product. Nevertheless, a few customers have experienced some problems with the training.

Problems/Solutions.—

Organizational Difficulties: Personnel and Instructional Materials.—The most significant problem faced by the CADAM training division was that of organizing the training staff and the training material to lower the cost and increase the consistency of the training itself. Creation of the program design department freed the trainers from the responsibility of developing their own training material. The self-instructional training package developed for the basic course also frees CADAM from some of the service costs (providing an instructor to teach the course, etc.) and offers customers the option of purchasing training for slightly more than half the cost of the instructor-delivered course. While not all CADAM courses are amenable to the self-study format, the training division plans to package the basic II terminal operations, analysis procedures, and 3-D piping courses as self-study programs.

Solution to the problem of organizing the staff and materials, while decreasing the cost, created another problem. Some of the instructors had difficulty accepting the change in focus in the revised basic course—from the individual instructor's interpretation and explanation to the highly structured and print-centered instructional material. These instructors point out that the new course allows for less interaction between students and instructors. Other instructors, who have taught the basic course so frequently that they felt themselves growing stale, believe that the new basic course allows them to aid the students' progress with more ease than in the past, and these trainers appreciate the opportunity to apply their efforts to the more advanced courses.

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*See p. 23 for customer response to the "reading-planning-performance" methodology.

**Since the final revision of the course was released shortly before the writing of this study, information on student evaluations of the final version of the course was not available.

*The training director intends to formalize the follow-up procedures once all of the customer courses have been revised.

The solution to this problem of mixed instructor response to the new training method is being achieved through a give-and-take process of gradual accommodation. The instructors are required to learn new techniques and methods which focus on facilitating the students' understanding of the print-centered material rather than on the instructors' own expertise and experience with the system. However, the division management points out that the instructors will be able to become experts in teaching specific aspects or applications of the system in advanced courses which will continue to require a large degree of teacher-student interaction. While the students lose some degree of personal interaction, they receive instructional materials which thoroughly cover each step of the process in a consistent manner and which can be used as readily accessible review material after the training is completed.

Trainee-Centered Problems.—As with other training programs in computer-aided manufacturing and design, aproximately 5 percent of trainees in the CADAM basic course exhibit resistance to it. CADAM training division representatives say the root cause of this is "computer anxiety," a syndrome with two major aspects: the trainees' fear that they will be replaced by a computer and the corresponding fear that they will not be able to master the "monster" that is replacing them.

In some instances, "computer anxiety" is accompanied by another negative response, labelled by CADAM trainers as the "It'll All Go By" syndrome (the belief that computer-aided design is a flash-in-the-pan trend which will never create significant changes in design work). Trainees who do show this type of resistance are in the minority and are, according to CADAM trainers, usually designers, engineers, or drafters nearing retirement age. While the growth of CAD/CAM has reduced the numbers of trainees who believe that "it'll all go by," "computer anxiety" remains a significant problem for some trainees. CADAM trainers address this problem by explaining that the system is a new tool that can only make their jobs easier. The student workbook for the basic course also helps the trainees to overcome their anxiety by, again, referring to the system as a tool rather than as a threat and introducing the students to the terminals within the first 8 hours of instruction by moving them into a hands-on exercise that is easy to execute and has minimal potential for failure.

CADAM trainers estimate that fewer than one-quarter of the initially resistant trainees (2 percent of the total student group) retain their resistance after the first two 2 days; they report that many such students have returned to take advanced courses. Approximately 1 percent of all trainees fail to learn the system, not because of resistance to the training, but because of a "mental block," or inability to understand what is required to operate the system.

Another problem—one experienced by the majority of trainees—is that the basic course presents such a large volume of information that most students do not grasp all of it during the week-long course. Extension of the course into a second week was rejected as a solution because the customer firms can rarely spare their employees for that length of time. The new instructional materials are designed to address the problem of "overload" by presenting the information in the building block pattern with built-in redundancies to reinforce knowledge of the previous steps. In addition, the new course material works as a reference guide once the training has been completed.

Evaluation of Present and Future Capacity to Meet Training Needs

Merrill Lynch states: "As users become more sophisticated, we envision a move toward general purpose mainframe computers at the high end application level for maximum performance and ability to do data base management . . . . This trend implies a change in character of some vendors toward being CAD/CAM system integrators."[9] CADAM's orientation to the systems integration approach, and CADAM management's belief that training is an integral element in that approach, may be the key to the future potential of both the software product and the training that supports it. However, it should be noted that under its installed user program IBM also markets CAD software produced by other firms.

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[9] *CAD/CAM Review and Outlook*, 1981, p. 2. The Merrill Lynch 1982 *CAD/CAM Review and Outlook's* user survey, however, found that among the overall disadvantages of mainframe systems are insufficient software and support, high initial expenses, and the fact that the entire system goes down when the CPU does.

Two of those software packages—CAEDS, developed by Structural Dynamics Research Corp., and circuit board design system, developed by a Canadian firm—address specific CAD applications and not the broad design and manufacturing market aimed at by CADAM; but the third package—CATIA, developed by Dassault Systems in France—does, according to an IBM representative, have some potential "overlap" with CADAM Inc.'s software applications. In addition, IBM also markets a CADAM training package, called a "Graphics Training Aid," developed by Westinghouse's Industry Motor Division in Roundtree, Tex. The Graphics Training Aid was purchased by approximately 50 companies in 1982, primarily those intending to set up their own internal CADAM training operations.

While neither Westinghouse nor IBM views the Westinghouse Training Aid, which most buyers purchase as a self-study package, as being in direct competition with CADAM system training, the Westinghouse package **does** give the customer the option of purchasing training other than that supplied by CADAM. Furthermore, CADAM training is also sold by independent engineering and consulting firms—one of which, according to one customer interviewed, delivered 2 weeks of "excellent" training to his employees. The "partnership" with IBM, then, does not give CADAM a monopoly on IBM's hardware customers—nor does the firm's own training department have a monopoly on CADAM training.

Customer Evaluations.—Six CADAM Inc. customers, most of whom had received training after either the interim or final revisions of CADAM basic had been completed, were interviewed. Most of them represented medium- to large-sized firms which had previous experience with either the CADAM system or other computer-aided design systems, and some are actively engaged in networking CAD and CAM capabilities. Responses to a request for an overall evaluation of the training—including content, delivery, and applicability to specific company needs—ranged from "reasonable" and "good" to "excellent." One customer, who had received CADAM training in January 1982, went to an outside consultant for further CADAM training a few months later and returned to CADAM at the end of 1982 for more training, said that training and other support supplied by CADAM was inadequate in January but had shown "great improvement" and "greatly increased attention to detail" by the end of the year.

Benefits.—One customer—who had made a 3-year study of the CAD market before purchasing a system—said that the real benefit of the training delivered by the CADAM training department, as opposed to CADAM training delivered by other vendors, is that the trainees learn how to make the most efficient use of the system in the shortest period of time. Most of the customers said that, after completing formal CADAM system training programs, they felt well prepared to embark on the most significant portion of the training—the period directly following the formal course when the systems are used for actual production work. During this 2- to 4-week period, most of those interviewed reported that their new CADAM system operators got "up to speed" (i.e., produced designs at rates which matched or exceeded manual drawing times) even faster than anticipated. Those who had purchased or were considering purchasing the self-study packages felt that this new option was a tremendous benefit, primarily because of the perceived need for ongoing internal CAD training.

Problems.—Aside from the problems mentioned in the preceding pages of this section, the most frequently articulated problem was that the terminals at the CADAM Inc. training center occasionally went "down" or had poor response-time. (None of the customers interviewed have had equipment problems at their own installations, however, and many reported "incredibly quick" response times averaging 0.15 second.) While the equipment problems at CADAM—which are currently being addressed—do not reflect on the trainers or on the training materials, they did create an atmosphere of frustration which colored the trainees' perception of the training course. One customer, whose firm is located in the Southeast, has had numerous problems with the CADAM hotline, which, he claims, is often inaccessible to Eastern customers because it only operates during business hours on Pacific time. This customer has lodged a formal request to encourage CADAM to extend its hotline hours to accommodate customers located in other time zones.

All of those interviewed agreed that CADAM training is extremely expensive relative to customer training provided by the majority of other computer-aided-design firms. While most accepted the high cost of the training as either a necessary evil or as the price of learning to be effective users of the CADAM system, one customer labelled the price of the training as "outrageous—highway robbery." Although most of those interviewed thought that the cost of the self-study packages ($650 per kit, as opposed to $1,250 per student for the Basic course) makes CADAM training a more reasonable investment, one believed that even the self-study package was "twice what it should be."

Training for Profit: Pros and Cons.—CADAM's training director points out that, while many hardware (and hardware/software) firms provide training free of charge to their customers—or at rates far below those charged by CADAM—by, in essence, folding the cost of training into the hardware or software prices, CADAM's procedure of pricing training to cover the operating and development costs of the training division creates certain benefits for both the customer and the training deliverer.

For one, customers get what they pay for—i.e., customers who require little or no training are not subsidizing the training of other customers. Secondly, he says, because training costs are frequently buried in equipment or operating costs, most companies do not recognize that good training is expensive to develop and deliver. It is for this reason, he believes, that training is often "too little and too late" and is often among the first support functions to be cut back during economic downturns; so that, along with recognizing that training is a necessity if sophisticated equipment is to be used effectively, company management must also recognize the **actual** costs of creating and maintaining training functions.

The status of training within CADAM's organizational structure—the fact that the training function is the sole responsibility of one of the four major divisions—indicates CADAM management's recognition that training itself is of pivotal importance in the CAD/CAM field. The scope and degree of CADAM's commitment to training is possibly unique in some respects. Certainly the relative size of the training division (8 percent of the firm's employees) is unusual,* as is the fact that the training director reports directly to the president of the firm.

Also unusual is the degree of flexibility and responsibility accorded to the training division. The division is responsible for providing "quality" training to support the software product and for making a profit. Also, it is given the flexibility, the resources, and the communicative channel with the product development department necessary to fulfill that responsibility. A comment by a training division representative provides a cogent description of the firm's approach to training in general: "We're trying to turn the old situation of training departments around. Most training departments are not given enough responsibility and accountability and have a subservient position in the company, reporting through many levels of bureaucracy. In a high tech field, training can no longer be handled in a subsidiary, low-level, low-priority fashion—it's too important. Things are too volatile and they change too fast."

By designating the training division as a profit-center and by providing it with the resources and organizational support to produce a well-designed training product, CADAM management has made an investment in the training itself. This means that the training product must be high-quality if the firm is to realize a return on its investment indirectly (in terms of product support) and in terms of direct profit from the training charges. Profit realized from the training is used to pay the training division's operating costs and to fund development of new training programs and refinement of already-existing courses.

As a profitmaking entity whose training product entails a great deal of expense—both to the customer and to CADAM—the training division runs the risk of, as one customer put it, pricing itself out of the training market. And when high prices are combined with a reluctance on the trainers' part to go beyond the contents of the basic course when students ask about advanced applications, the CADAM training division also runs the risk of giving some customers the impression that their specific needs will be attended to only insofar as they do not extend into areas covered by further training, i.e., which entail further purchases of training.

On the other hand, statements by trainers in some user firms support the assertion of CADAM's training director that the common practice of burying training costs in operating or other expenses keeps management unaware of the real costs of providing training. It is possible that what is perceived as an "outrageous" training cost actually reflects a reality that most industries are not used to seeing. The training division's cognizance of the need to lower training costs while maintaining quality resulted in development of the self-study packages that both reduce cost and enable customers to train future generations of users with the same instructional material. It remains to be seen whether the self-study package will solve the problem of high cost.

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*It should be noted, however, that the ratio of training division personnel to other CADAM employees would be more difficult to achieve in a larger firm.

The firm's capacity to meet the direct training needs of future CADAM customers will depend on its ability to maintain its gains in improving the quality of the courses and to develop new courses while keeping its prices within reasonable limits. CADAM's approach to training presents an interesting conundrum. On one hand, CADAM illustrates that significant time and money spent to make training a "first priority" can be seen as investments rather than as begrudged expenses. The firm also illustrates that the investment of those resources in well-designed and adequately tested training can increase productivity and profit. On the other hand, it may be a matter of questionable prudence for CADAM to be among the few software providers pricing their training "realistically." Can they "educate" the entire population of users as to the actual costs of training, or will other training vendors who offer "CADAM" instruction at a lower price deprive the training division of significant numbers of students?

Although CADAM training appears to be of a high standard, it also appears to some customers that CADAM's packaging of training as a high-priced commodity sometimes impinges on its overall effectiveness by limiting the information available to trainees in the basic classes. It would seem then, that there is an attitudinal problem on the part of both the recipients and the provider of training, each with his own expectations of the proper form of training and the behavior of trainers. More explicit communication between the trainers—who must use the limited time at their disposal to present a great deal of material in a systematic fashion—and the customers—who have varying needs which may not always mesh with the highly structured basic course—would ameliorate this difficulty.

Case Study 4
Programmable Controller Training Program

International Brotherhood of Electrical Workers, Local 11 Los Angeles County Chapter, National Electrical Contractors Association

Summary

The Los Angeles Electrical Training Trust is the training arm of the Joint Apprenticeship Training Committee of the International Brotherhood of Electrical Workers (IBEW) Inside Construction Local 11 and the Los Angeles Chapter of the National Electrical Contractors' Association (NECA). The Training Trust, supported by Local 11 members and the electrical contractors who employ them, provides a 4-year apprenticeship training program and voluntary courses for Local 11 journeymen.

In the late 1970's, the Trust began addressing the need to provide journeyman training in the skills required to install, troubleshoot and maintain the electronic devices that were beginning to replace a number of the hard-wired electrical devices involved in inside-construction in factories, plants, and offices. This study focuses on one set of course offerings provided by the Trust—a series of three courses on the installation, programming, and troubleshooting of programmable controllers.

Background: Los Angeles Electrical Training Trust

The Los Angeles Electrical Training Trust (ETT) was established in 1964 to support educational and training programs for apprentices and journeymen covered under the collective bargaining agreement between IBEW Local 11 (Inside Construction) and the Los Angeles Chapter of the National Electrical Contractors' Association (NECA).* As provided for in the Labor Management Relations Act of 1947, the Trust is jointly operated by local union and management representatives and is supported by regular contributions from Local 11 members and their employers. Under the terms of the current collective bargaining agreement, Local 11 members contribute 5¢ for every hour worked into the Trust, while their employers contribute 15¢ for every employee-hour. While the primary responsibility of the Trust is to provide apprenticeship training, the Los Angeles ETT—along with a number of the other local IBEW training organizations in the United States—also operates an active journeyman skills improvement program.

All apprentice and journeyman courses are held in training facilities that are either owned, leased, or rented by the Trust. To accommodate the approximately 7,000 journeymen and 650 apprentices in the Local's Los Angeles County jurisdiction (covering 4,069 square miles) the Trust maintains five training centers: one "Metro Facility" in downtown Los Angeles, and one in each of the district's four other dispatch areas. The Metro Facility, opened in March 1981, contains seven classrooms and 8,000 square feet of laboratory area (including a $300,000 process instrumentation lab, as well as laboratories for welding, house wiring, conduit bending, motor controls, transformers, fiber optics, high-voltage cable splicing, air conditioning, and fire alarms and life safety instruction). Two of the dispatch area training facilities have permanent laboratories, while the other two occupy rented space which is converted into temporary laboratories for training purposes.*

Training Trust Administration and Staff.—In accordance with the provisions of the Labor Management Relations Act, the Trust Fund is controlled and administered by a six-member Board of Trustees with equal union-management representation. In addition to the Board of Trustees, the Los Angeles ETT is also served by five Joint Apprenticeship Subcommittees (JASC—one in each of the district's five dispatch areas) and the Joint Journeyman Educational Advisory Committee (JJEAC). On the permanent staff of the Training Trust are the director, a staff representative in charge of apprenticeship training, a staff representative for journeyman training, and a senior instructor. The majority of the courses are taught by journeyman electricians who serve as part-time instructors for the Trust.

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*Local 11 is one of 365 IBEW inside construction locals, whose membership work primarily for independent electrical contractors. The IBEW also maintains manufacturing locals, serving electrical/electronic manufacturing firms; maintenance locals, whose members do in-plant maintenance; utility locals serving public power companies; and telephone locals. Because members of Inside Construction Locals often work for a series of small to medium-sized contracting firms which do not have the resources to provide in-plant skills training, the Inside Construction Locals are among the most active in delivering journeyman training under the auspices of Joint Apprenticeship Training Committees.

The National Electrical Contractors Association maintains 135 local chapters throughout the United States. The Los Angeles Chapter currently has 230 member contracting firms, 35 of which have 30 or more permanent employees and often provide design and engineering as well as installation services. The remainder of the members employ an average of 10 to 12 full-time workers. NECA members provide electrical contracting services to a wide variety of customers, including manufacturing firms, powerplants, newspapers, hospitals, schools, and offices. A number of NECA members are also members of the IBEW.

*By the end of 1983, the Trust hoped to have established permanent training facilities in all of the dispatch areas.

The Trust director is appointed by the trustees and is responsible for the ongoing operation of the training programs. The current director, appointed in 1978, has had previous experience as both an IBEW journeyman and an electrical contractor. Both staff representatives have worked as IBEW journeymen and foremen, and both have had previous experience working with training and educational programs. All of the approximately 25 part-time instructors who teach the apprenticeship programs are credentialed as part-time instructors by the State of California. The 58 instructors who teach journeyman courses are not required to obtain State teaching licenses; approximately half of them, however, are credentialed.

Philosophy of Training: General Goals.—The major goal of the Electrical Training Trust is to deliver comprehensive apprenticeship training and provide journeymen with the opportunity to improve or reinforce existing skills and develop new skills required by the changing electrical/electronics field. According to the ETT's director of journeyman training, the line between electricity and electronics is beginning to dissolve; electricians intent on keeping their skills current, therefore, must develop new skills in electronics and computer-aided equipment.

Because of the voluntary nature of journeyman training, the Trust's educational philosophy also stresses motivation and creating an awareness of new skill needs to encourage journeymen to take advantage of the training courses offered. Individual motivation and self-initiative are especially significant, since approximately 25 percent of the membership is hired for relatively short installation jobs out of the union hiring hall. Of the remainder, approximately 60 percent are permanently employed and 40 percent work for two to three contractors per year.

Another aspect of the Trust's training philosophy is that it is the right of each journeyman who works at least 6 months per year to take any course offered in the skill-improvement program if he or she has completed the prerequisite courses. To avoid discouraging voluntary participation in the program, no grades are assigned at the end of the courses, and (for the majority of courses) no selection criteria are applied. The introduction of coursework on computer-based equipment like programmable controllers and process-instrumentation devices has, however, created exceptions to the general free-enrollment procedure. Because not all of the students who enrolled in the intermediate programmable controller courses had a solid grasp of the fundamentals taught in the basic course, selection procedures have now been instituted for that course. The process instrumentation program—a lengthy series of courses totalling 795 hours—requires students to pass an evaluation as an admission requirement and to pass examinations before proceeding from one course to the next.

Training Overview.—The Los Angeles Training Trust delivers required courses for apprentices and "pending examination wiremen" and voluntary courses for journeymen. Apprentices take a total of 840 hours of work-related classroom instruction at the Trust, extending over a 4-year period (3 hours per night/2 nights per week).* Related instruction courses include electrical code, mathematics, blueprint reading, first aid, pipe bending, welding, instrumentation, basic transistors, and electronics. Applications for the apprenticeship program are accepted every 2 years in Los Angeles. During the most recent application period, 1,650 candidates applied for the 100 to 200 apprenticeship openings anticipated over the next 2 years. New apprentices are admitted to the program on the basis of their rank score from the oral interview.**

"Pending examination" (PE) wiremen are experienced electricians who have not gone through the apprenticeship program but who instead become members when their employer signs an agreement with the Local. The PE program originated in Los Angeles in 1980 and has now spread throughout California and into some other States as well.* PE wiremen receive journeyman wages but are required to take an evaluation examination and to attend a concentrated 2-year, four-semester course series to reinforce their knowledge through formal study and to upgrade their skills. At the end of the program, they take the formal journeyman's examination to achieve full journeyman status.

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*The L. A. Trust's apprenticeship program is based on the 4-year program offered by the National Joint Apprenticeship and Training Committee in Washington, D.C. While the International sets guidelines for apprenticeship training, Locals have flexibility in setting their own programs. The Inside Construction Local in Detroit, for example, requires 672 hours of related instruction, delivered once every 2 weeks (8 hours per day).

**Of the 1,650 recent applicants, 1,150 passed the qualifying examination, which focuses on mathematics skills. Those who qualifed on the basis of the examination were then interviewed and were ranked from 1 to 1,150 on the basis of the interview. As apprenticeship openings occur over the next 2 years, candidates will be called according to their placement on the list.

Both the apprenticeship and the PE programs are administered through the Los Angeles County Schools' Regional Occupational Program, which serves as registrar for the two Trust programs discussed above.

Approximately 2,000 journeymen completed voluntary skill-improvement courses in 1981-82. Journeyman courses range from 3-week reviews of recent changes in the national electrical code to 13-week courses in advanced blueprint reading to a 3 1/2-year series of courses on process instrumentation.** The journeyman skill-improvement program is focused on reinforcing core trade skills and introducing new skills in demand in the local marketplace. Among those new skills are those required to install, program, troubleshoot programmable controllers, process instrumentation skills, and test and splice fiber optics cable.

Programmable Controller (PC) Courses

Planning and Development.—The need for coursework in programmable controllers was first brought to the attention of the Training Trust in 1978 by members of the Joint Journeyman Educational Advisory Committee (JJEAC). One of the committee members—a general construction manager for a large contracting firm that designs, engineers, and installs computerized systems for materials handling and process control—played an instrumental role by convincing the committee of the need, by providing advice on prerequisite coursework and equipment, and by recommending potential instructors.

Following the advice of its "area expert," the committee recommended that the Trust first develop a motor controls course to aid in preparing interested journeymen to take the more advanced PC courses. Westinghouse's Standard Control Division in El Monte, Calif., proved to be extremely helpful in the development stage, both by providing equipment at a greatly reduced rate and by recommending one of its applications specialists to be the course instructor. The curriculum for the first programmable controller course was developed by the Westinghouse specialist, reviewed and modified by JJEAC to increase its focus on the specific needs of Local 11 journeymen, and approved by the Board of Trustees late in 1980.

The first class was offered in October 1981, and the course has now become a staple offering of the Trust's journeyman skill improvement program. In the fall of 1982, the Westinghouse specialist who developed and taught the basic course began teaching an intermediate course, PC III, to graduates of the basic course. PC II, a hands-on course covering similarities and differences of four of the major programmable controllers on the market, will be offered in the summer of 1983.

Goals and Objectives.—Specific goals and objectives of the programmable controller courses support the major objective of the Training Trust's journeyman skill improvement program, which is to provide Local 11 members with the opportunity to develop knowledge and skills in all areas of electricity/electronics applicable to employment opportunities in the Los Angeles area covered by the Trust agreement. This entails not only meeting current needs, but attempting to forecast future needs so that the Local will be able to provide a trained work force when opportunities occur. Courses that develop skills in high-technology fields such as programmable controllers, process instrumentation, and fiber optics are considered by the Trustees and the JJEAC to be crucial areas of education and training for journeymen who want to keep pace with the skill requirements of the local marketplace. In the words of the Trust's director of journeyman training, "The only things we have to sell are our skills and knowledge—these must be pertinent."

Since the Trust was established to serve both union members and the contractors who employ them, its goal in offering the programmable controller courses is twofold: to provide appropriate skill training to Local 11 members, and to meet the needs of signatory contractors, more and more of whom are making installations involving programmable controllers. The specific objectives of the series of PC courses offered by the Trust are to train journeymen to install, provide power to, program, and troubleshoot programmable controllers. The goal of PC I is to provide a basic introduction to installation and programing requirements so that a graduate of the course could, under the direction of a skilled foreman, aid in PC installations on the job. The goal of the intermediate course is to provide additional information and practice in programing and to teach troubleshooting techniques to enable members to do installation work with less supervision.

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*In many areas of the country, experienced electricians who enter Inside Construction Locals when their shops are organized automatically become full-fledged journeymen. Approximately 400 P. E. wiremen are now taking courses at the L. A. Training Trust.

**Process instrumentation is the application of electric, electronic, and/or air controls to regulate pressures for measuring fluids or gases and for indicating and controlling levels, temperatures and flow of liquids or gases. Students in the process instrumentation program are taught how to inspect, calibrate, install, tune, and troubleshoot computer-aided instrumentation and process-control systems used in chemical and petrochemical plants, refineries, breweries, food processing, and other industries.

With the addition of the PC III course, the PC series will fulfill its overall objective—to familiarize advanced students with installation, programing, and troubleshooting techniques specific to the major PC systems in use in the Los Angeles area in order to provide them with increased work opportunities.

Administrative and Instructional Staff.—The Trust "staff representative" who directs the journeyman skill-improvement training is an active supporter of "high-technology training" for journeymen. The journeyman training department took major responsibility for locating the equipment and the instructor for the original PC course and for ongoing coordination of what is now a series of courses on programmable controllers.

Until the first few months of 1983, all of the programmable controller courses were taught by a single instructor, a Westinghouse applications specialist employed by the sales and customer support group of the Standard Control Division's Numa Logic Department. His prior technical experience includes work as an IBEW journeyman electrician—then as a draftsman, nuclear power engineer, and control panel designer. Previous to his employment by the Training Trust as a PC instructor, he had taught a series of courses on programmable controllers to employees of the Los Angeles Department of Water and Power. By the spring of 1983, four new instructors—Local 11 journeymen who have either taken previously offered PC courses at the Trust or have on-the-job experience—will begin teaching the basic course. In addition, they have completed customer courses, paid for by the Trust and delivered by Allen Bradley, Modicon, and Westinghouse—all major producers of programmable controllers in the United States.

Equipment.—The "Metro Facility" of the Training Trust contains four classrooms and three classroom/labs, one of which is available for PC courses. In addition, PC classes are also offered on a rotating basis at training sites in four of the district's dispatch areas. As of this writing, the Trust owns two Westinghouse 700 series Numa Logic Programmable Controllers, which are transported by the instructor from one training facility to another as the occasion demands.* The administrative staff of the Trust is currently in the process of purchasing programmable controllers manufactured by Allen Bradley, Modicon, and Texas Instruments in preparation for the PC III course to be offered in the summer of 1983.

Costs and Funding.—The journeyman skill-improvement courses are supported entirely by Training Trust funds. Most cost items for the programmable controller courses were not available (administration, instructor salaries, student materials, or classroom rental). The two major items of equipment currently in use—the Westinghouse programmable controllers, valued at $25,000 each—were purchased by the Trust for a total of $10,000. In addition, the Trust has set aside funds for the purchase of the other three PC systems to be used in the advanced course.

Costs to Students.—Tuition and instructional materials are free of charge to eligible journeymen and apprentices (see Selection, below). However, to encourage students to complete the courses, a $10 deposit is charged at the beginning of every course and is refunded to those students with satisfactory attendance records.

Selection Procedures and Enrollment Trends.—

Selection—Journeyman skill-improvement courses are open to all members of Local 11 who have worked 6 or more months out of the preceding year for signatory unions.** Apprentices are discouraged from doing so until they have learned the fundamentals of the trade. To date, no apprentices have completed the basic course.

Until recently, no enrollment control existed for either the basic or intermediate PC courses, aside from the necessity of completing the basic course

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*Though the Metro Facility provides secure storage space for equipment, the other training sites do not. Furthermore, classes have, in the past, been offered concurrently at more than one facility. The compact, transportable equipment therefore gives the Trust the flexibility to offer classes at more than one site.

Since the Training Trust is supported by a small proportion of the fringe benefits attached to the wages of working members of the Local and by contractors who are signatories to the trust agreement, (PC I) before signing up for PC II.* Since, however, regular attendance is the only formal graduation requirement, some graduates of the basic course have signed up for the intermediate course without the prerequisite skills and knowledge to benefit from the more advanced instruction. In February 1983, a new policy was established whereby members who enroll in PC I take an entrance examination covering motor control theory. Those who do not pass the exam are encouraged to take the motor controls course offered by the Trust before continuing with the basic PC course. Admission to PC II is now at the discretion of the instructor, who will base his decision on a review of completed homework exercises required in PC I. When the advanced course, PC III, is delivered in the summer of 1983, only those whose homework in PC II exhibits a thorough understanding of the intermediate course will be accepted. Those who are not accepted into PC II and PC III will be encouraged to retake the preceding course to bring their skills up to the required level.

Enrollment Trends/Attrition.—According to the Westinghouse instructor, the PC I and II courses have been very well attended, sometimes drawing as many as 32 enrollees for a single course. The complexity of the coursework, however, and the need of some of the PC I enrollees for background coursework in motor controls and solid-state electronics, has resulted in an overall attrition rate of approximately 33 percent.*** While the preferred class size is 12, classes have ranged in size from 8 to 18 students. (Especially large classes are split in two, which, until the recent addition of the two extra instructors, presented problems for the Westinghouse trainer, who had to teach classes twice a week to accommodate all interested students.) Both enrollment and attrition are less in PC II than in PC I.

The employment situation of the journeyman electricians who enroll in the PC courses varies considerably. Some are permanently employed by signatory contractors;* some work for single contractors for long stretches of time (6 to 12 months) on major installation jobs; others work "out of the hall," i.e., are not permanently or semipermanently employed but rather are hired for relatively short jobs out of the union hiring hall. Because of the current economic situation in Los Angeles, a growing number of the students in PC courses work out of the hall.

Two additional factors play a part in this enrollment trend: 1) large electrical contractors who provide design and engineering services as well as installation often provide in-house training for their Local 11 employees who install programmable controllers, and it is these contractors who do most of the PC installation in the county, and 2) a number of smaller contractors who are prepared to do installations involving programmable controllers—and who would be likely to encourage their employees to take the PC courses or to hire course graduates—have been affected by the construction slump.

Curricula: PC I—PC III.—PC I and PC II were both designed to be 18-hour courses, delivered in 3-hour segments 1 evening a week for 6 weeks. However, because of the amount of material to be covered in the basic course, recent PC I courses have been extended to 7 weeks. PC III, currently in the development stage, will be from 16 to 24 hours in length and will take place on the weekends to enable students to attend intensive 8-hour-a-day classes.

- *PC I.*—Students in this introductory course learn terminology, the basics of the theories behind programmable controllers, how to address the equipment, how it works, and basic installation, programming, and applications. Since the majority of students enter the class with limited experience in solid-state controls, the first two sessions are devoted to basic theory—an introduction to logic and to Boolean algebra (session I), an introduction to solid-state controls, and a comparison between solid-state and electromechanical devices (session II).

  Programmable controllers are not introduced until the third session, when students learn what programmable controllers are, how they compare to electromechanical controls, and some basic PC applications. Installation and basic programing (including an overview of input and output devices and special functions involving timers, counters, and other devices) are covered in session IV. Sessions V-

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employees covered under the IBEW Local 11 agreement who have worked at least half the work-days of the year previous to enrolling in classes have contributed to the trust fund and are therefore eligible. Occasionally, members who have worked less than the normally required 6 months are allowed to attend classes. These decisions are made on a case-by-case basis.

*Students with previous experience working with programmable controllers on the job may also test-in to the intermediate course without having completed PC I.

**Successful completion of homework assignments is not a requirement for graduation, only for entrance to the next course.

***In recognition of the potential for attrition, the instructor has instituted the following practice. An entrance test concentrating on motor controls theory is given on the first night, and those interested in participating were then interviewed and were ranked from 1 to 1,150 on the basis of the interview. As apprenticeship openings occur over the next 2 years, candidates will be called according to their placement on the list.

*Contractors who operate "union houses" and are signatory to the collective bargaining agreement between Los Angeles NECA and IBEW Local 11.

VII are primarily devoted to discussion and practice of programing for specific applications. In addition, session VII also covers "multiplexing," i.e., carrying out multiple functions simultaneously in an independent but related manner, an operation that often involves combining several signals so that they can be handled by a single device.

- *PC II* provides graduates of the PC I course with the opportunity to practice the basic programing techniques they learned in PC I and to learn more advanced programing applications. For example, they learn to program the PCs to control a "bad parts detector" on a manufacturing plant conveyor system by writing and inputting programs for counting the total number of parts on the line, counting the number of faulty parts, and for rejecting the parts that are flawed. In addition, the students complete a number of troubleshooting exercises: the instructor puts "bugs" into the classroom equipment and requires the students to tell him why the equipment is not working, how they would fix it, and what the result will be once the adjustment is made.

  Both the programming and the troubleshooting experiences are of use to inside wiremen who, when they install programmable controllers, often run a basic program for testing purposes and troubleshoot equipment problems that may occur. Some wiremen may also work for contractors who may be called back to a facility to troubleshoot and repair equipment that they installed initially.
- *PC III.*—This course, now under development, will teach graduates of PC II how to install, program, and troubleshoot the major models of programmable controllers currently on the market. Accordingly, the course will focus on teaching the students the differences and similarities between the Westinghouse Numa Logic 700 Series used in PC I and PC II and the models produced by Allen Bradley, Modicon, and Texas Instruments. The Trust is currently proceeding with plans to purchase the equipment, and the Westinghouse instructor is designing the course materials.

Instructional Materials and Teaching Methods.—Instructional materials for the PC I course were developed by the Westinghouse instructor specifically for use in Training Trust courses. Using some material from the Westinghouse Numa Logic programing and applications manuals and some original material, he devised an instructional package specifically geared for skilled tradespeople with knowledge of electricity but not necessarily of electronics. The same approach—based on relating the principles, theories, and operation of programmable controllers to the theory and operation of electrical and electromechanical devices—is used in lectures and hands-on exercises. When teaching Boolean algebra, for example, the instructor relates it to common electrical problems the trainees already understand, and specific Boolean algebra problems given in class and for homework are based on actual wiring problems the electricians would be likely to run into in the field.

Another example of this approach would be the instructor's method of teaching the theory and operation of timers and counters, which are among the basic components of PC systems. He explains the use and purpose of timers and counters by relating them to relays and electromechanical devices; explains how programing takes the place of wiring when dealing with programmable controllers; and assigns in-class, hands-on exercises to reinforce the basic concepts.

The initial exercise is always reinforced by a second exercise which is very similar to the first. Homework, including reading and problem exercises, is assigned weekly to further reinforce the material taught in class and to lay the basis for the next week's lecture and laboratory work. Although no final grade is given, tests are conducted at the beginning and end of the course and are supplemented by weekly quizzes—all of which help the instructor to know what to emphasize for each individual class.

Both PC I and PC II are approximately 70 percent lecture, 30 percent hands-on. In PC II, the programing and troubleshooting exercises become more difficult as the course progresses, as the students are taught to reapply what they have already learned to increasingly difficult problems. No specially designed training manual is used for PC II. Instead, students use Westinghouse programing and applications manuals. Students in PC III will have access to the programing and application documentation for all of the systems taught and will learn to write basic programs and modify existing programs on these systems. In addition, they will learn to identify similar problems in all the models, along with methods for troubleshooting the various systems. Students in this advanced course will be expected to complete a great deal of reading on their own time to free up the majority of the class time for practical installation, programing, and troubleshooting exercises.

To increase the amount of hands-on time available to each student in the PC II classes, a new system was inaugurated in the 1983 winter-spring schedule. Each student in these classes had the opportunity to take a programmable controller for a week of at-home practice. In addition, students in future classes will also have access to the new training equipment presently being purchased, which will be made available to them at the Metro Facility when it is not being used for training purposes.

Course and Student Evaluations.—

Evaluations of the Courses—Students complete written evaluations of the course, the instructor, the facilities, and the instructional material. While there is no formal course evaluation by the trustees, the JJEAC, or the Training Trust staff, both the IBEW Local and the local NECA chapter provide unofficial channels for evaluation of the course by both contractors and journeymen. Contractors who employ union members who have completed the class give NECA informal evaluations of the workers' skills, and this information is transmitted to the Trust through the contractor-members of the Trustee committee and the JJEAC. Similar informal evaluations reach the Trust via the union representatives who sit on the various committees.

Evaluations of the Students.—Since journeyman skill-improvement courses are taken on the students' own time and on a voluntary basis, no course grades are given, and it is not necessary to pass a final examination to graduate from any journeyman course. However, the new selection criteria for admission to PC I and PC II will require that students in the less-advanced courses illustrate the ability to proceed with more-advanced coursework as an admission requirement to PC II and III.

Results

As of February 1983, 89 Local 11 members had completed the basic course and 29 had completed the intermediate course. Since the Trust has no formal follow-up mechamism for tracking graduates of the journeyman courses, it is difficult to assess the overall results of the training in terms of job performance and/or expanded employment opportunities. Interviews with the Training Trust staff, the PC instructor, students, and contractors have produced some data, which, though limited, illustrate some training results in specific instances.

Of nine journeymen interviewed in the January 1983, PC II class, one was currently working on a PC installation, one had been hired from the hall to work on PC installations in the past, and another was preparing to become one of the new PC instructors. All three were taking the course to increase their applications and troubleshooting skills, and one noted that the course was especially helpful in teaching him to recognize troubleshooting problems. The other six had not had the opportunity to work with programmable controllers on the job, but were taking the course for two reasons: 1) to prepare themselves for future opportunities, and 2) because they believed it was incumbent on them to develop the skill to work with the electronic and computer-aided equipment they now see to be replacing electromechanical devices in many operations.

Those who worked out of the hall stated that the PC courses they had taken would give them a distinct advantage in obtaining work, since they would be able to respond to "specialty calls" (requests for workers with specific skills) for PC installation when these come into the hiring hall.*

Six of the eight contractors interviewed provided in-house PC training for their Local 11 employees.** One, however, said that he "expects" his employees to take the Training Trust PC courses and that eight of his employees who had taken the course had improved their skills. While one large contractor who provided formal training classes did not see the need for his employees to take the Trust classes, he did support the training for other, smaller contractors. Three others who provided their own training did not have a present need for more employees skilled in PC installation. They could anticipate, however, a future need and thought that the course graduates would be attractive hiring prospects.

One employee of another of the contractors had taken the class but, because the contractor had an adequate number of employees who were experienced in PC installations, the course graduate had not yet had the opportunity to do any installations. He would, though, be "first in line" for such work should the need arise. Another contractor, who had hired two course graduates, noted that the PC and process instrumentation courses provided by the Trust save contractors time and money by enabling them to make installations without first having their employees trained by equipment manufacturers' representatives.

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*Although no formal refresher courses are provided for those who do not have the opportunity to practice their new skills on the job, Local 11 members may maintain and increase their skills by taking the more advanced courses. PC III is so designed that students can benefit from repeating it one or more times to get additional hands-on practice.

**Training ranges from formal classes to on-the-job instruction.

In terms of direct results of the training, employers' and students' comments indicate that a relatively small proportion of the graduates (possibly a third) have had an opportunity to make use of their training on the job. Since, however, graduates of the courses delivered as far back as 1981 were not available for interviews, the actual number of graduates currently using their skills may, in fact, be much larger.

For the remainder of the graduates, the primary result of the training has been to increase their employment potential and to offer them the opportunity to work with a higher level of technology which, according to all the journeymen interviewed, is "more interesting and less dirty" than the "wire pulling" and pipe bending they often do on installation jobs. According to the Westinghouse instructor, who is also engaged in sales and service of PCs and other control system components, today's $370 million PC market represents a tremendous growth over the last 3 years. He predicts that, by 1990, the market will have grown to at least $500 million and that one result of that growth will be an ever-increasing need for properly trained workers on the part of electrical contractors who install (and often design and engineer) control systems for manufacturing facilities, processing plants, newspapers, and numerous other enterprises.

According to the chapter manager of the Los Angeles chapter of NECA, the training provided by the Trust gives small- and medium-sized contractors who do not have the resources to train in-house the opportunity to bid on installations incorporating PCs and other sophisticated controls. Not only will the Trust classes train their permanent employees, but they also help to develop a pool of trained workers in the hiring hall who can respond to the PC specialty calls from contractors. This issue—i.e., the future potential of the graduates and the potential opportunities their new skills create for local contractors—will also be evaluated in section III. The remainder of this section will focus on problems directly affecting the training courses, and the solutions to those problems.

Problems/Solutions.—Because so many of the students do not have the opportunity to work with PCs on the job, it became increasingly clear to the instructor that the amount of class time available for hands-on experimentation and practice on the equipment was inadequate. Two new procedures, both instituted in the first few months of 1983, lessen the effects of this problem.

The extension of the PC I course to seven sessions has added 3 additional hours of hands-on time, upping the total class hours available for laboratory work from 6 to 9. While the extra class time is helpful, students in a class of 12 (the average size of Training Trust PC classes) still have less than a few hours each on the equipment. It is the second solution, therefore, which is the most promising: in the PC II classes that began in January 1983, all of the students took one of the PC consoles home for a week or more. This allowed them to apply what they learned in PC I, and to experiment with some of the programing applications they covered in the PC II. According to the instructor, an "immense" improvement was seen both in the weekly homework and in the final examination once all of the students had ample hands-on opportunities.

Another new practice, soon to be instituted, will allow for even more hands-on opportunities. The Metro Facility laboratories will be made available during the day and on those nights when PC classes are not in session. This will enable advanced students in PC II and students in PC III to practice on the Allen Bradley, Modicon, and Texas Instruments programmable controllers, while PC I and less advanced PC II students can continue to use the Westinghouse systems at their own homes. Since there is usually little or no overlap in the scheduling of PC I and PC II courses, this system should provide ample hands-on opportunities for any student willing to avail himself of them.

A second problem, closely related to the first, is the lack of time in an 18- to 21-hour course to cover a great deal of complex material. Here, again, the extra session recently added to PC I will be of help, as will the recent emphasis on encouraging those who do poorly on the entrance examination to first take the motor-controls course. The instructor also encourages beginning students to take the Trust's process instrumentation course, which covers the fundamentals of solid-state electronics and provides those students who take it with basic skills and information applicable to the PC courses. The more information about motor controls and solid-state electronics entering PC students have, the easier it becomes to move quickly through the introductory material in the first two sessions and spend more class time on PC programing, installation, and applications.

Another related problem is the widely varying knowledge and skills of the students. The instructor estimates that, in a class of 12, four or five usually exhibit a ready grasp of the material. Another two or three demonstrate a less-than-complete understanding, while the remainder are unable to make the transition between the principles governing electricity and those governing electronics and do not grasp the different approach required by programing as opposed to hard wiring. On the other hand, he notes that many students who "don't get it" the first time around show great determination and repeat the basic course one, two, and even more times.

Because the courses offered by the Trust are free of charge to the students, motivated students who nevertheless require additional time to absorb the material can learn at their own pace—and, according to the instructor, "once it clicks, the worst hurdle is over and the rest comes with practice and application." On the other hand, the great variety of aptitude and learning speeds within a single class does present a problem for the instructor and holds back the faster learners. The newly instituted enrollment controls should relieve this problem to some extent, especially in PC II and III, but it is doubtful that it can be entirely solved. Similar problems have been noted in classes delivered by reprogrammable equipment vendors and by many teachers of introductory courses in a vast array of disciplines.

A final problem noted by the instructor is also one that is common to other industrial training courses involving reprogrammable equipment. The problem—resistance on the part of many students in the basic course to the new concepts, theories, and techniques that must be learned—manifests itself in the Training Trust PC I classes as an initial attitude of skepticism held by as many as half of the first-night enrollees. The instructor, therefore, devotes a portion of the first night's lecture to a general discussion of the growth of solid-state controls and computer-aided equipment and the present and potential effects of the changing technology on an electrician's job.

He then presents his own perception of the trade—that, in the very near future, if not in the immediate present, there will be two kinds of electricians: technicians and those who, as the technology expands, will be stuck with lower level jobs. Technicians, he says, will get better, steadier work, while the others will spend more and more time in the hiring hall.

While most of the students respond positively to his appraisal, a few maintain their skepticism and either drop out of the class or continue attending without applying themselves to the course material. In many cases, it is older workers who are either nearing retirement—or who face the prospect of unlearning much of what they have spent years learning—who are the most resistant to the new technology. On the other hand, a number of older students have learned rapidly and well.

Evaluation of Present and Future Capacity

Present Capacity.—According to local and national IBEW representatives and local representatives of the National Electrical Contractors Association, the Los Angeles Electrical Training Trust has the financial resources and the solid backing of both management and labor required to maintain its current level of high-technology training and to extend that training into other high-technology fields as the needs arise. Local IBEW and NECA officials believe that their working relationship is among the best in the country, and this sentiment is echoed by individual contractors, union members, and the Training Trust staff. The relationship between the union and the contractors' association is, of course, a crucial factor affecting the administration, direction, and the specific training courses offered by the Trust, since the trustee committee, the educational committees, and all of the subcommittees have equal representation by labor and management.

High-technology training courses like those in programmable controllers and process instrumentation are clearly advantageous to both the union and the contractors' association. According to the Westinghouse instructor, PC manufacturers are already having difficulty keeping up with installation and service support requests. As the PC market expands, manufacturers like Westinghouse will—as Allen Bradley, Texas Instruments, and Modicon have already done—turn more and more to support system houses operated by electrical contractors and distributors to provide design, engineering, installation, and service to the end-user.* This will result in expanded opportunities for electrical contractors and a correspondingly expanded need for electricians trained in PC installation and service.

PC III training is especially beneficial to the small contractor who operates independently of the major manufacturers and who does not have the advantage of distributing the equipment or of customer referral by the manufacturers. Such small-to-medium contractors must be able to handle installation and service of a variety of models in order to bid on a larger number of contracts and to purchase the best and most cost-effective systems for his customers' specific needs. It is, therefore, to their obvious advantage to have permanent employees who are well-versed in a number of different systems and to be able to place PC "specialty calls" in the hiring hall when they need extra workers for a large installation.

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*Whereas Allen Bradley, Modicon, and Texas Instruments use system houses for sales as well as design, installation, and support services to the customer, Westinghouse plans to continue selling its own systems and to recommend certain system houses for engineering and service.

Local contractors interviewed had installed programmable controllers in a wide variety of enterprises, including food processing plants, refineries, breweries, battery plants, and shipyards. A number of contractors specialize in conveyor systems and had installed PC-automated conveyors in manufacturing and processing plants and in airports. Two of the larger contractors had, in the past, installed PCs in auto assembly plants—including Ford, GM, Toyota America, and Honda. Now, however, they are feeling the effects of the economic downturn and are forced to look out of the area for large, heavy-manufacturing installation jobs.

Although the depressed state of some segments of the local construction market has resulted in fewer contracts and less work for electricians at the present time, both management and union officials are committed to increasing the training effort. The relatively favorable construction market in years past has produced a sizable trust fund, making it possible for the trustees to invest in the equipment and courses they believe are necessary to prepare the workers to compete for present and future jobs. Furthermore, some segments of the market show signs of an upswing. There has, for example, been a recent resurgence of the petroleum industry in the area, which has produced work for contractors and electricians skilled in process instrumentation.

Current Training-Retraining Issues.—

*Higher Wages for Increased Skills?—*One of the most significant training-related issues facing the union and the contractors' association is the feeling on the part of a number of contractors and some union members that those journeyman electricians with high-technology skills should draw higher wages than those who do not upgrade their skills.

Supporters of the double wage structure for journeymen fall into a number of camps. Some support the notion of a "super-journeyman," i.e., a journeyman who is, essentially, a technician with skills in such areas as solid-state controls, process instrumentation, nuclear instrumentation, and/or fiber optics and who would draw a higher hourly wage than journeymen with "low-technology" skills. The reasoning is that those electricians who are already journeymen and have, essentially, been "caught short" by the new technology should not be "punished" for not developing new skills, but that those who do upgrade their skills should be given monetary incentives for doing so.

Other supporters of the double-wage structure believe that a "sub-journeyman" classification should be created for those without high-technology skills. Subjourneymen would make less money than fully fledged journeymen with technician-level skills and, again, would have a monetary incentive to develop expertise in electronics.

Other variations of support for a double, or a sliding, wage scale would not change traditional occupational classifications but would, in some manner, provide higher wages for increased skills. This could be achieved by classifying PC installation, process instrumentation, and other work involving high-technology skills as "specialist categories." This means that journeymen working on jobs involving those skills would receive a premium wage for the duration of that job. Two such specialist categories already exist: cable splicers, who do hazardous work on high-voltage cables; and electricians who are also certified welders. Both receive extra pay when working on jobs requiring these extra skills. Those who would make PC installation and process instrumentation into specialist categories maintain that this would provide an additional incentive for electricians to upgrade their skills without creating sweeping changes in the occupational structure of the union.

Local and national union officials are opposed to the above-mentioned variations of a wage differential. The business manager of Local 11 points out that the creation of a "super-journeyman" category would place a burden on contractors, who are already paying journeymen a regular wage of more than $23 an hour in Los Angeles. On the other hand, he believes that the creation of a "subjourneyman" classification would defeat the philosophy of the apprenticeship program and would serve as a disincentive for apprentices, who would have a double hurdle before becoming fully fledged journeymen. Creating a "specialist category" for PC installation, he believes, is a stop-gap measure that would, while creating a monetary incentive for electricians, also place monetary restraints on contractors. His approach—which is also the approach of training and education representatives at International headquarters—is to focus on upgrading the general skill level of Local 11 journeymen to include skills in programmable controllers and other solid-state electronic skills.

While both the local and international union representatives recognize that their approach is more costly in terms of time (i.e., that higher wages for high-technology skills would induce more journeymen to take advantage of training opportunities), they also believe that the industry cannot afford another wage increase. According to Local 11 representatives, those electricians who do not develop the skills required by the advancing technology will be less and less capable of performing the work and will, eventually, "be phased out" because of inability to obtain work. International IBEW representatives concur in that prediction and emphasize that the value of a broad-based apprenticeship program is that it creates a flexible tradesperson skilled in a wide variety of tasks. Highly paid specialists, they argue, are too limited for the type of work required by the vast majority of contractors.

Future Capacity.—The future capacity of the Los Angeles Electrical Training Trust to provide training and education in programmable automation and other increasingly technical electronic applications is dependent not only on the internal capacity of the Trust to provide courses but also on the continuing strength of the union itself. A 1980 electricians' strike resulted in higher wages, but also caused the loss of 50 to 100 small contractors from the Los Angeles NECA chapter. The strike, which occurred in June, was followed by a depression in the local construction market, which put further strains on the remaining union contractors. At present, the approximately 40 percent of electrical contractors in the Greater Los Angeles Area who still maintain union shops must contend with nonunion contractors who can often underbid them because of the lower wages received by nonunion electricians.

Both the Local and the International recognize the problem that the higher union wage scale poses for the contractors. What the union has to offer, they say, is responsible negotiation; an insistence on apprenticeship training and an emphasis on journeyman training; and a skilled pool of available labor in the hiring hall that obviates the necessity of "permanently" hiring in times of plenty and firing in lean times. Los Angeles NECA representatives and local contractors interviewed specifically emphasized their belief that the management of Local 11 is both responsible and responsive to the needs of the contractors.

The L.A. Training Trust—which stressed the value of increased training when times were good—is emphasizing it even more in times of difficulty. It is building its capacity to offer more—and more advanced—courses to those who have the individual motivation and who have responded to the constant encouragement to take advantage of the training opportunities that exist. The PC III course should take instruction in programmable controllers well beyond the "familiarization" level of the PC I course. The process instrumentation program will produce "technicians" qualified at four advancing levels: device level, loop level, system level, and instrumentation/process control level. The Trust is also currently preparing instructors to teach fiber optics courses, and is exploring the possibility of purchasing a Heathkit robot for a proposed robotics course.

In addition, the Los Angeles Trust has offered to assist IBEW locals in other nearby jurisdictions by opening the Trust laboratories to other Locals by reciprocal agreement and helping them to design high-technology courses. Information provided by the Los Angeles ETT and by other local IBEW training organizations funded by JATC trusts is also being used by the International training organization to develop PC courses that, within the next 6 months, should spread to at least 100 other training sites. The international organization is also developing materials to assist local organizations in teaching semiconductor and fiber optics programs.

It is, however, utlimately the responsibility of individual union members to support the Local's and the International's claims of quality training by voluntarily upgrading their skills in high-technology fields. The Training Trust itself is now facing the problem of attempting to provide "quality training" while, at the same time, providing the opportunity for all of the eligible Local 11 members to attend the courses. The evaluation and selection procedures instituted for the process instrumentation and programmable controller's courses go against the grain of the Trust's basic philosophy, but they nevertheless represent problems that are now being addressed.

To maintain credibility, the Inside Construction Locals must continue to provide workers whose skills are appropriate to the contractors' needs. If training organizations like the Los Angeles Training Trust cannot upgrade the skills of significant numbers of journeymen through the provision of voluntary courses, the union may be forced into giving serious consideration to the "subjourneyman" concept—which, of all the variations of the notion of wage differentials based on high-technology skills, seems to be gaining the most adherents.

Case Study 5

CAD/CAM Operator Training Program: Glendale, Calif.

Summary

The Glendale CAD/CAM* operator training program was sparked by the spirit of innovation and cooperation on both the State and local levels. Funded by a combination of Federal and State moneys and sponsored on the State level by two State agencies, the Glendale program is one of six pilot programs in California which bring together colleges, industries, and local government agencies to train California residents to work in emerging or expanding technological fields. The Glendale program, which trained participants with drafting backgrounds to utilize computer-aided design systems for mechanical design and printed circuit board detailing, was a cooperative venture between Glendale Community College, local industries, the City of Glendale, and other local organizations. At the end of the first cycle of the program, 7 of the initial 12 enrollees were employed as CAD/CAM operators and three others found related drafting jobs. At this writing, the second cycle is still in session.

Background

Coordinated Funding Project for New Vocational Education Programs.—The Coordinated Funding Project—administered under the joint sponsorship of the Chancellor's Office of California Community Colleges and the State's Employment Development Department (EDD)—is an innovative, State-level response to the need to develop vocational education programs in emerging and expanding technologies in a period of budget cuts and reduced resources for educational programs. The statewide project was created in response to recommendations of a legislative "Task Group" set up in 1979 to review vocational education in California and to suggest how vocational education funds could be utilized most effectively. In its final report, the Task Group made the following recommendations: 1) adoption of State-level administrative policies to allow for consolidation of resources,** 2) greater private-sector involvement in vocational training, and 3) expansion of programs linking worksite training and classroom instruction.

The Coordinated Funding Project is a combined effort on the part of the Chancellor's Office and the EDD to consolidate State and Federal funds from three sources—the Comprehensive Education and Training Act (CETA), the California Worksite Education and Training Act (CWETA), and the Vocational Education Act (VEA)—to support pilot education and training programs involving a high level of coordination between colleges, private industries, and (in some instances) local government bodies.

In November 1981, the project staff sent Requests for Proposals (RFPs) to all of the community colleges in California asking for concept papers outlining innovative programs in emerging or expanding technologies or labor-intensive occupations that combine classroom instruction with worksite training in order to: 1) upgrade basic work skills, 2) provide entry-level training, or 3) enhance or build on the skills of displaced workers. The colleges were specifically requested to design programs for occupations not included in their current curricula and to seek new solutions for long-existing problems. Specific objectives to be met by each local program included the following:

- to provide vocational training programs meeting specific local employers' needs;
- to involve local employers and other appropriate entities in project planning, curriculum design, and training implementation;
- to provide effective job skills training to the project participants;
- to obtain continuing employment with career advancement potential for project participants; and
- to incorporate the resulting curriculum into ongoing college vocational education programs.

Over 50 colleges responded to the RFP, and in January 1982, four individual colleges and two college consortia were awarded contracts totalling $800,000 (for all six programs). The top-ranked proposal was a program submitted by Glendale Community College (GCC) to train CAD/CAM technicians. In February 1982, GCC was awarded $84,271 to train 24 participants (12 in each of two training cycles);* shortly thereafter, five other schools or consortia of schools were awarded contracts to train participants in fields such as computer-aided drafting, computer-assisted machining, digital electronics and microprocessors, business machine and computer repair, and solar and alcohol technology and wood products manufacturing.

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*Computer-aided design and computer-aided manufacturing.

**It was noted in the report that the existence of a "myriad of programs providing occupational training" had resulted in fragmentation of funding and administrative procedures and created a significant obstacle to effective coordination.

The remainder of this study focuses on the CAD/CAM technician program operated by Glendale Community College. In the fall of 1982, a new State initiative, titled "Investment in People," set aside $3,400,000 to fund other college programs of a nature similar to those supported by the Coordinated Funding Program. Glendale submitted an Investment in People proposal containing a modified and expanded version of its original CAD/CAM program and was awarded $55,885 to train additional participants in various computer-aided design applications.

Glendale CAD/CAM Operator Training Program.—The Glendale program is an attempt to demonstrate the feasibility of coordinating a variety of funding sources (CETA, CWETA, and VEA) as well as the efforts of a variety of participating organizations and agencies. The project is a joint effort on behalf of Glendale Community College, Jet Propulsion Laboratory, Singer Librascope, Computervision, the City of Glendale, and the Glendale Private Industry Council. The remainder of this introductory section is devoted to brief descriptions of these participating organizations and the part each plays in the CAD/CAM program. Section II describes the project activities of each major player in greater detail.

Glendale Community College.—Glendale Community College (GCC), designated as the training program operator, is fully accredited by the Western Association of Schools and Colleges as a 2-year institution providing both general and specialized education to youth and adults. Its four primary objectives are to: 1) educate students to meet the lower division requirements of a university or 4-year college, 2) provide post-secondary vocational education for students preparing for entry-level positions and for employed students upgrading their skills for job advancement or to meet new job requirements, 3) post-secondary education for "personal improvement" (i.e., coursework taken to satisfy individual interests and which does not lead to a degree or certificate), and 4) adult education "below the lower division level," which includes coursework leading to the high school diploma, career and vocational classes, citizenship classes, and classes serving special interest needs of the community.

GCC was founded in 1927 and, until recently, was under the jurisdiction of the Glendale School Board, which was also responsible for the primary and secondary-level education system in the district. In the fall of 1982, a new school board, solely responsible for the Glendale Community College District, was created. This action is especially significant in relation to the school's regular vocational education programs and to special projects like the CAD/CAM operators program in that the president/superintendent of the new school board has expressed a specific commitment to vocational education and is a member of the Glendale Private Industry Council (see below). Approximately half of the college's 10,200 students (5,200 full-time; 5,000 part-time) are either enrolled in technical or vocationally-oriented certificate or transfer programs* or take one or more vocational education courses.

The CAD/CAM Operators' Program was coordinated by the college's director of special programs and was taught by the senior drafting instructor.

Jet Propulsion Laboratory (JPL).—JPL was established by the California Institute of Technology (Cal Tech) as a private, nonprofit research and development laboratory.** Located on the outskirts of Glendale in La Canada, Calif., JPL employs approximately 4,600 people: approximately 2,400 are engineers and scientists; 2,000 are support personnel; and 200 are engaged in manufacturing prototype products (see following paragraph). When the laboratory was founded in 1945, its major activity was to complete rocket research and development for the U.S. Army. In 1959, it became a National Aeronautics and Space Administration (NASA) research center. Today, although its principal contract is still with NASA, JPL also has research and development contracts with the Department of Energy, the Department of Defense, the National Institutes of Health, some local agencies, and some private industries.

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*Each training cycle consisted of 12 weeks of formal classroom/laboratory instruction, followed by 200 hours of worksite training at the participating companies.

*Certificate programs are primarily business or technical programs designed for students preparing to enter the job market upon completion of the program. Transfer programs are designed for students planning to continue their education at a 4-year institution.

**Cal Tech continues to manage JPL's contracts. According to a JPL section manager, the difference between the research conducted at Cal Tech's main campus in nearby Pasadena and that conducted by JPL is that JPL is product development-oriented whereas the research on the campus is primarily academic in nature.

As a NASA contractor, the principal focus of the laboratory's activities is lunar and interplanetary investigation—tracking and acquiring data from satellites and probes in NASA's deep space network. Currently operating at a funding level of just over $350 million, JPL concentrates on research, development, and design of products. Its manufacturing activity, therefore, is limited to the production of prototypes and is a proportionately small part of the lab's responsibilities. For this reason, JPL has little computer-aided production equipment; it does, however, have approximately 500 computers (ranging from mainframes to micros) which are primarily used for computer-aided design and other computer-aided engineering applications such as analysis and simulation of engineering data.*

According to JPL's Design and Mechanical Support Section manager, JPL's concentration on development, design, and "first article delivery" means that the laboratory uses computers and computer-aided systems primarily as analytical tools rather than as production tools. The current focus of the Design and Mechanical Support Section is to attempt to save money and other resources in the preliminary stages of manufacturing by infusing into the design process the ability to do simultaneous analysis, material selection, and selection of fabrication work in an attempt to create a product design that could be implemented without wasting material or having to reconfigure tooling in the manufacturing process.

JPL's Design and Mechanical Support Section participated in the Coordinated Funding Project partially because of its growing need for CAD/CAM operators since 1980, when the section installed its first Computervision CAD/CAM system. According to the section manager, the introduction of computer-aided design into the section enabled it to bid on and complete more work in less time and also—because the design engineers' time is considered to be too valuable to do detail and documentation work on their designs—created a need for a new category of employee—"CAD/CAM operators" who are skilled in drafting and in the operation of computer-aided design systems.*

Approximately two-thirds of the participants in the Coordinated Funding Project receive "work site training" at JPL—hands-on laboratory work on the Computervision terminals that both complements their classroom instruction at Glendale Community College and assists JPL engineers in the detailing and documentation of their designs. JPL has hired five trainees from the first cycle of the program and may hire some from the second phase.

Singer Librascope.—The remaining third of the original 12 Coordinated Funding Project participants received worksite training at Singer Librascope, a division of the Singer Co. engaged in the production of military equipment.

Like JPL, Singer Librascope required trained Computervision operators and looked on the Coordinated Funding Project as a means of acquiring employees trained to company specifications. While all of the trainees received the same classroom instruction at GCC, their worksite training at Singer Librascope and JPL differed. Those who completed their laboratory training at Singer Librascope were trained to work on printed circuit board (PCB) designs, while the JPL trainees worked on mechanical designs.**

Computervision.—Computervision—for many years the largest producer of turnkey CAD/CAM systems—participated in the Coordinated Funding Project by providing free training for the GCC drafting instructor in its Los Angeles training center.*** The classroom instruction provided to the trainees was an adaptation of four of Computervision's customer training courses. Computervision also assisted by providing reduced-price training documentation.

Glendale Private Industry Council and the City of Glendale.—The Glendale Private Industry Council (PIC) was formed in 1979 under Title VII of the Comprehensive Employment and Training Act. Title VII, the Private Sector Initiative Program, was aimed at giving business and industry

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*"Computer Aided Engineering (CAE) . . . includes those computer systems designed to facilitate Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Business Systems (CABS), the Interactive Computer Graphis (ICG), and all those other systems that facilitate the solution of engineering problems. It plays a key role in areas such as design, analysis, detailing, documentation, N/C programing, tooling, fabrication, assembly, quality control, testing, and all aspects of management of the data base relevant to the particular product under consideration." Donald D. Glower and Lindon E. Saline (ed.), *A Response to Advancing Technologies* (Washington, D.C.: American Society for Engineering Education, 1982), p. 7.

*Previous to the installation of the Computervision terminals, the section contracted drafting work to independent drafters or drafting firms. It is anticipated that the CAD systems and the new CAD/CAM operators will eventually replace the need for contract drafters.

**The students themselves were given a choice of industry site on the basis of their interest in either mechanical or PCB design.

***Computervision also supplied free training to two high school teachers, who became CAD instructors in a high school training program developed at approximately the same time as the Coordinated Funding Project's CAD/CAM operator program.

a major role in designing and implementing employment and training programs tailored to local private-sector needs.* Although the authority of business and industry representatives on a number of PICs across the country has sometimes been limited by the control of the local elected officials (designated as CETA Prime Sponsors) over PIC activities, the Glendale PIC has effected a viable working relationship between local government, education, and industry representatives.

In order to describe the role played by PIC in the Coordinated Funding CAD/CAM Operator Program, it is first necessary to provide a few paragraphs of background material on PIC itself and its relationship with its Prime Sponsor, the City of Glendale. PIC's board is primarily composed of business and industry representatives but also has representation from local government and community groups, including the Glendale Unified School District, the Employment Development Department, and the Department of Social Services. In 1981, PIC merged with the CETA Advisory Council (which was under the jurisdiction of the City of Glendale, in its role as CETA Prime Sponsor).

The merger occurred at a time when a number of other PICs and Prime Sponsors in other localities were also consolidating councils; in some locations, the mergers were seen by one or the other of the groups as "take-over bids" and were accompanied by vituperation on both sides. In Glendale and in some other locations, the consolidation of councils was seen as a reinforcement of an already effective cooperative relationship. According to the present PIC director, PIC and the city have yet to disagree on matters of program or policy, largely because there is general agreement that PIC should act as the policymaking body while the city acts as the administrative body.

Another factor that enhances PIC's ability to function in a coordinated manner is that it has eliminated duplication of services by designating specific types of training delivery to specific groups in the Glendale area. Glendale Community College, for example, provides classroom instruction and skills training under contract to PIC; another designated contractor is responsible for work experience for youth, for example, and yet another takes responsibility for in-school youth programs. PIC board members and staff believe that these measures have helped it to become the top-ranked council in terms of job placement in the DOL region covering California, Nevada, and Arizona.

PIC played two roles in the CAD/CAM Operators Program. Its formal role was to provide administrative services for the program, including contract compliance, recordkeeping, participant tracking and reporting, operational monitoring, and technical assistance. These services were formally subcontracted by Glendale Community College to the City of Glendale, which, as the administrative arm of the consolidated council, performs similar services for PIC-operated programs.

The other role played by PIC was informal but crucial to every aspect of the program from conception to delivery. The Glendale PIC defines its responsibilities in a broader context than the actual operation of training programs for economically disadvantaged participants. According to both the PIC director and the chairman, PIC must have a sense of—and be active in—the community as a whole in order to be effective in its formal function of delivering private-sector training programs for the community's disadvantaged residents. The board and staff members, therefore, perceive their function to be that of facilitators, or brokers, who can act to bring together representatives from business, education, and government to create the kind of working partnership they believe is the intent of CETA, Title VII, and its successor, the Job Training Partnership Act.

It was in its role as a facilitator that PIC had its greatest impact on the CAD/CAM Operator Training Program. The proposal that won the Coordinated Funding Project contract for Glendale Community College was conceived by the PIC director and was an adaptation of a computer-aided design program for high school students proposed by the PIC chairman, who is also the manager of JPL's Design and Mechanical Support Section and a member of the* school program, which was designed to familiarize high school students with CAD/CAM technology and to encourage them to continue their education in computer-aided technologies.

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*The successor to CETA, the Jobs Training Partnership Act, retains the private-industry councils created under CETA and expands their responsibility and authority. In order to be certified under the new act—which requires a service delivery area with population of 200,000 or more—the Glendale PIC consolidated its council with the nearby Burbank PIC in 1983.

*Because the Glendale Coordinated Funding Project was not a PIC-sponsored program, the question of conflict-of-interest did not arise in relation to JPL's role. Conflict of interest is, however, a debated issue in the new Jobs Training Partnership Act. According to a report released by the National Governors' Association, "at least 15 states place total bans on designated officials from conducting business either with the State, or local municipalities, or other governmental entities of which they are members." Some private-industry council members in some localities are, therefore, prohibited from allowing PIC training programs to be operated in or for their places of business. A number of private industry councils, on the other hand, operate on the principle that PIC board members can have the most impact by opening up their own businesses or industries to PIC programs, thereby providing training and employment opportunities to eligible participants and, at the same time, illustrating by example that such programs can be effective for

The college program, on the other hand, was conceptualized as a means of serving the participating students and companies alike by training the students to fill immediate employment needs at JPL and Singer. Both programs were designed to serve their respective educational institutions by upgrading teachers, introducing new technological curricula, and providing courses that would eventually be incorporated into the ongoing curricula of both the college and the high school.

The CAD/CAM program, then, resulted from the synergistic relationship between PIC, the college, and industries like the Jet Propulsion Laboratory. It derives also from the leadership of individuals like the JPL section manager, whose activities in other arenas (as PIC chair and as School Board member) provided him with both the broad-based perspective and the position to effect the coordination called for in the State's Coordinated Funding Proposal.

CAD/CAM Operator Training Program

Goals and Objectives.—Overall goals of the CAD/CAM Operators' Program are: 1) to develop a training program in CAD/CAM which could be incorporated into the community college system in Glendale, and which could be replicated at other community colleges, and 2) to train 24 participants to be CAD/CAM operators. Apart from those overall goals (which are primarily those of the college), PIC, JPL, and Singer Librascope each had additional objectives for their project participation.

Private Industry Council representatives viewed the Coordinated Funding Project as an opportunity to strengthen the bond between the college and local industries by demonstrating that the two entities could work together in a project that could benefit each while also helping the community by training and employing local residents. In particular, PIC hoped to showcase the college as a resource for local industries which could, by assuming industrial training responsibilities, help the companies save on training expenses. PIC also saw its participation in the project as a way to partake in an effort to build the community's capacity to engage in high-technology training which—in the opinion of key staff and board members—may not be appropriate for the majority of CETA-eligible residents without the necessary background skills.* By helping the community to establish a high-tech training capacity, PIC hoped to establish a training resource which could eventually be used by economically disadvantaged participants whom PIC would first provide with prerequisite skills such as drafting.

Although Jet Propulsion Laboratory and Singer Librascope had a major objective in common—that of obtaining employees specifically trained to their work requirements—their secondary objectives differed. One basic difference was that Singer required students trained as detailers—i.e., CAD/CAM operators who do detail work on designs created by others—whereas JPL wanted trainees who would do some basic design work and eventually become full-fledged designers.

Consequently, JPL informed all of the students who completed their worksite training at the laboratory that those who would be hired would be expected to continue their education (at company expense) at a 4-year college. A further objective held by JPL was to build the college's capabilities so that the lab could draw on it as a training resource in the future. Computervision's object in participating in the project was to support its customers—JPL and Singer Librascope—by assisting in the instruction of their future employees, and to assist the college by helping it to develop the capability to create an ongoing computer-aided design course utilizing Computervision equipment.

Planning and Development.—The State-level planning for the Coordinated Funding Project and much of the local-level planning for the Glendale program have been outlined in section I of this study. This section will, therefore, discuss the program development efforts that took place after the selection of Glendale as a contract recipient.

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employers. In the NGA report cited above—which specifically addresses the question of conflict-of-interest in regard to the new Job Training Partnership Act—the Georgia Employment and Training Council specifically recommends that "Federal regulations concerning conflicts-of-interest which are presently being drafted exempt PIC members from prohibitions against conducting business in their own or any other service delivery area where: 1) such member notifies in writing his potential conflict of interest to the council or administrative entity; 2) such member refrains from voting or in any way participating in the decision to award contracts; and 3) the council or administrative entity makes as a part of its record the reasons for awarding the contract to one of its PIC members and why the award is in the public's best interest." "Implementing the Job Training Partnership Act. Technical Brief: Conflict of Interest," National Governors' Association, December 1982. Issue paper presented for response.

*Because the CETA funds used in the Coordinated Funding Project were discretionary linkages funds earmarked for project administrative expenses, the project operators were not bound to meet CETA selection criteria, although they were urged to include as many CETA-eligible participants as possible.

Previous to the writing of the proposal, both JPL and Singer Librascope had made commitments to participate in the program. Once the proposal was accepted, PIC contacted Computervision and secured its commitment to provide training for the Glendale instructor. The school's engineering drafting instructor, who also works part-time at JPL as a senior engineer, was chosen as the CAD/CAM program instructor and was given the responsibility of designing the curriculum.

To prepare for his curriculum-writing and instructional duties, the instructor attended a summer-long upgrading program. He began his training by completing a week-long Computervision self-study course at JPL, followed by a week of on-the-job training in JPL's CAD/CAM operations. During the following 9 weeks, he attended 100 hours of training at Computervision's Los Angeles training center, completing customer courses in mechanical design and electromechanical design. The week-long courses at Computervision were supplemented by on-the-job training at both Singer Librascope and JPL. At the completion of his training, the instructor designed the classroom training curriculum for the program, aided by advice from JPL and Singer employees.

Because the students would be receiving classroom instruction at the college and laboratory training at one of the participating firms, much of the program development effort included setting up formal mechanisms for coordinating between JPL, Singer Librascope, PIC, and the school. That coordination involved logistics planning. Discussions between the college and the two companies resulted in a plan whereby students would attend 3-hour lectures at the college two mornings a week and laboratory training two late afternoons or evenings a week (to avoid students competing with employees for workstations).

Administrative and Instructional Staff.—As the primary program operator, Glendale Community College had fiscal responsibility for the project. It was also responsible for delivering classroom and laboratory training and for appointing a program counselor to act as liaison between the students, the college, and the participating companies. The college's director of special projects for vocational education served as the overall program administrator. Administrative services were subcontracted to the City of Glendale/Private Industry Council, while the college retained the activities of recruitment, screening and selection, counseling, and placement. The college's engineering drafting instructor was responsible for delivering the classroom instruction, overseeing the laboratory instruction at JPL, and coordinating with the two companies.

The instructor, a past graduate of Glendale Community College, has a bachelor's degree in industrial design from California State University at Los Angeles, a master's degree in industrial design from California State University at San Jose, and a vocational education teaching credential from the University of California at Berkeley. His previous industrial experience includes work at Columbia Broadcasting Corp. as a designer, at General Electric's Nuclear Engineering Division as a packaging engineer, and at IBM as a senior design engineer.

Facilities and Equipment.—Classroom instruction was delivered at Glendale Community College, which has a fully equipped traditional drafting classroom, but no computer-aided design stations. Eight of the initial class of 12 students attended the laboratory portion of their training at JPL, which has four Computervision terminals dedicated to training purposes. The remaining students had their laboratory instruction at Singer Librascope, which has four Computervision terminals in its engineering department for use by program trainees and Singer employees alike.

Program Funding.—Glendale Community College received $84,271 from the Coordinated Funding Project ($3,243 from CETA; $19,533 from CWETA; and $61,495 from VEA). The CETA funds and approximately half of the CWETA funds were subcontracted to the City of Glendale to cover administrative services, and the remainder of the CWETA funds paid for a portion of the instructor's retraining (4 weeks of on-the-job training at JPL and 4 weeks at Singer Librascope). The VEA funds were devoted primarily to covering the direct costs of the training for the 24 participants. In addition to the State funding, the participating firms provided the following in-kind contributions: 100 hours of computer-aided design training for the Glendale instructor (Computervision) and equipment-use-and-maintenance costs for the

CAD/CAM terminals valued at $97,200 (JPL and Singer Librascope). Glendale Community College contributed space and utilities totaling $3,800.

Recruitment and Selection/Participant Profile.—In May 1982, the college sent flyers announcing the CAD/CAM program to 2- and 4-year colleges and Employment Development Department in the Los Angeles County area. Applicants were required to be U.S. citizens; be 18 years old or over; have a high school diploma or general equivalency diploma; be able to pass a security clearance; and have completed the following college-level courses:

- one semester of basic mechanical drafting;
- one semester of advanced mechanical drafting;
- one semester of descriptive geometry; and
- or equivalent work experience.

Recommended but not required were the following:

- one semester of electronic drafting;
- one semester of machine design;
- one semester of basic electronics or machine shop;
- prior work experience in the above areas; and
- or equivalent work experience.

After making formal application for the program at the Glendale CETA office, the candidates took a written examination at the college on June 12. The applications contained questionnaires requesting information on the applicant's long- and short-term goals, attitude, and motivation. The formal examination contained practical drafting problems requiring a knowledge of tolerance, dimensioning, scaling, clearances, interferences, and electrical schematics. From the initial group of over 50 candidates, the college representatives selected 18 on the basis of both test scores and indications of practicality, willingness to do detailed work for long stretches of time, and motivation shown on the application questionnaires. Once the college made the initial selection, representatives from JPL and Singer interviewed the students and made the final selection.

The majority of the 12 students selected as program participants for the first session, which began September 13, had previous machine shop or drafting experience. Over half had 2-year drafting certificates, and five of those students also had 2-year certificates in electronics or machining. The average age of the group was 23. Two participants were female; one was Hispanic; four had incomes below the poverty level; one was a displaced homemaker; and four were veterans.

Similar selection and recruitment procedures were followed for the second group of 12 participants, who began the coursework in February 1983. The second group was approximately 50 percent female and included four Hispanics and three Orientals.

Classroom Instruction and Laboratory Training.—The students received 12 weeks of formal instruction (6 hours a week of classroom instruction and 6 hours of Computervision CADDS 3 terminal training per week). Because no terminals were available in the college classroom, the classroom instruction was strictly devoted to theory, which was then applied in practice in the company laboratories. The GCC instructor was responsible for classroom instruction and for monitoring the laboratory sessions at both JPL and Singer Librascope. Instructional materials consisted of four Computervision training documents—CADDS 3 Pocket Reference, CADDS 3 Mechanical Basic Guide, CADDS 3 Mechanical Design Workbook, and the CADDS 3 Printed Circuit/Electrical Schematic Basic Guide*—and Computervision's self-study audio/print learning package, "Introduction to CADDS 3 Operation," which teaches the basic concepts and commands needed to use CADDS 3 applications software.

Curriculum.—The curriculum was designed to include the introductory material covered in the self-study package plus three Computervision CADDS 3 customer courses: 1) Basic Mechanical Design, 2) Advanced Mechanical Design, and 3) Basic Printed Circuit/Electrical Schematic Design. The first week of class was devoted to an overview of CAD/CAM technology, during which the instructor lectured on CAD/CAM system hardware and software, turnkey CAD/CAM systems, computer-generated visualizations, computer-aided design and computer-aided manufacturing processes and applications, and the integration of CAD/CAM into industrial processes.

During the second week, students were introduced to the basic techniques for using CADDS 3 software, concentrating on terminology, log on/off procedures for entering and leaving the system, and basic command language. The lecture portions of the second week of study covered the format of command language syntax—made up of verb + noun + modifier strings which the operator uses to execute a command by inputting a function (verb), such as "insert," plus a geometric entity (noun), like "line," plus a modifier which describes the geometry, such as "parallel" or "perpendicular."

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*CADDS is Computervision's "Computer-Aided Drafting and Design System." Students were required to purchase the pocket reference and the mechanical design workbook; the school supplied them with the two basic guides. (Computervision, which normally sells the basic guides for $75 each, provided them to the college for $30 each.)

The students also learned how to use the system's online documentation feature, which aids the operator by prompting him or her with information on, for example, what "nouns" (line, circle, arc, fillet) go with specific "verbs" (insert, delete, or combine, for instance) and what modifiers can be used with particular verb/noun combinations. During the laboratory sessions, the students completed portions of the Computervision audio cassette/workbook course under the instructor's supervision.

Following the basic operations segment, the students spent 2 weeks (24 hours) learning to use the system for basic mechanical design. This segment included the fundamentals of part creation (i.e., how to use the system to create lines, circles, arcs, and fillets) and part filing (how to file a drawing of a part in the system); how to erase, modify, and manipulate elements; and basic projections (how to reproduce objects on planes or curved surfaces by projecting their points to create 3-D objects).

During the following 2 weeks, the students learned how to insert dimensions in mechanical drawings (including linear, angular, radial, and diameter dimensions, dual dimensions, and extension lines and arrows); how to use construction aids, such as grids and layers; how to size and scale part-drawings; "zooming" (focusing in on a small section of the drawing on the screen or widening the focus to include the full drawing); and how to insert textual notes and symbols to accompany their drawings. The laboratory work during this segment consisted of working through specified sections of the *CADDS 3 Mechanical Design Workbook* and completing individual projects involving the creation of 2-D and 3-D parts.

The next 3 weeks (weeks 7-9 of the course) were devoted to printed circuit/electrical schematic (PC/ES) applications. The first lecture in this segment covered the differences between mechanical and PC/ES applications and operations. The students then learned to create electronic symbols (called "nodal information" in Computervision terminology) and to digitize[*] and annotate electrical schematics, which the computer then converts into a "net list," i.e., a list of all the start- and end-points for specific wire paths on the board. By the eighth week, the students were creating PC component diagrams, digitizing simple PC boards, and then using the system to merge the printed circuit boards and to automatically route the result.[*] They then learned to edit their PC boards[**] and to record the parts and computer files (i.e., to store both the PCB drawing and the schematic and net list information in the computer). As in the mechanical segment, the students were required to complete individual projects using the terminals in the laboratories.

During the next 2 weeks, the students worked on specific electro-mechanical design problems dealing with the design and packaging of printed circuit boards. The last week of the course was devoted to review and to the final examination.

Instructional Methods.—When he developed the curriculum, the instructor was faced with a problem intrinsic to the structure of the program: how to modify the Computervision courses, which were designed for students with 4-hour-a-day access to terminals, to be taught in the Glendale format (6 hours a week of classroom instruction; 6 hours a week of laboratory practice). A number of his teaching methods were therefore dictated by the peculiarities of the situation. A portion of the classroom time was devoted to lecture on, and class discussion of, the theory behind the laboratory work to be done in the following lab session. Because of the lack of equipment, the instructor used the chalkboard to demonstrate the basic principles, and the students completed pen-and-paper exercises simulating the terminal exercises they would perform in the laboratories.

The remainder of the classroom time was spent in group discussions of individual problems encountered in the laboratories. (Although a number of the students were reticent about discussing those problems in a group situation, all were required to do so in order to provide them with experience in communicating problems to co-workers and attempting to solve them in a group situation.) The instructor's object in this was to simulate the industrial environment to the greatest extent possible. Students were expected to produce professional-level work; were expected to meet strict deadlines for their twice-weekly lab work and for the projects required at the end of each section; and were trained to solve the sort of practical problems they would face on the job.

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[*] "Digitizers" are instrumented surfaces on which the location of a point, selected with an associated cursor unit, is automatically converted into digital, x-and-y coordinate data suitable for transmission to a computer (Turnkey CAD/CAM Computer Graphics, A Survey and Buyer's Guide, pp. 3-22). In the PC/ES operation described above, "digitizing" means to use a stylus to locate points which will eventually be connected by wires on the finished circuit board.

[*] The "merge" process tells the system that all of the components that exist on the board must be hooked up, based on the net list, so that the information on the net list is actually merged into the printed circuit board design. In the "routing" process, the system automatically indicates to the operator the lines that physically connect the digitized points.

[**] The editing process is necessary because the system cannot always route every wire on every board. For example, if the system cannot get from point A to point B without intersecting another point and so grounding-out the wires, the human operator must drill a hole in the board, run the wire along the bottom side, and drill back up to the component side so that he can continue to run the wire on an unobstructed path.

Students worked two-to-a-terminal in the laboratory sessions, using the "partner system" that Computervision trainers use in their customer classes. Each student would work on the terminal for approximately 15 minutes at a time, while his or her partner would monitor the operation to make sure it was being done correctly and would provide assistance when necessary. This system, according to Computervision, allows each partner to both observe and perform specific operations and therefore reinforces the learning process. Because JPL had four terminals located in a dedicated training lab and because the laboratory operates on a flexible schedule, the students who did their laboratory work at JPL had 4 to 6 extra hours a week of terminal time. According to the instructor, the students were all so highly motivated that they had to be forcibly ejected from the laboratory at 11:00 p.m.

In addition to the classroom and laboratory work, the instructor arranged for two field trips—one to the Computervision Training Center in Los Angeles, and one to Weber Aicraft to observe the IBM/CADAM system in a production environment.

Examinations and College Credit.—Students were given an examination at the end of each major course segment (basic operations, mechanical application, and electrical applications) and took a 3-part final examination covering mechanical design, electrical design, and basic drawing. All but one of the students passed the final test and received three units of college credit for the course.*

Student Evaluations.—In written evaluations completed at the end of the classroom/lab portion of the program, the trainees gave both the instructor and the course high marks. Most, however, stated that the course would be improved by more terminal time and more time spent on printed circuit board design. (See "Results" section for more recent evaluations of the course by session I trainees now working at JPL and Singer Librascope.)

Worksite Training.—Once they completed the classroom/laboratory portion of the program, the 11 remaining students began worksite training at JPL and Singer Librascope. This portion of the training consisted of 200 hours of work, which in the case of the eight trainees, was divided into 10, 20-hour weeks. Because Singer Librascope was anxious to place its trainees on the permanent payroll as soon as possible, the 200 hours of training for the three Singer participants was condensed into 7 weeks. Trainees in both locations worked on actual production designs and were paid salaries of $5 per hour by the firms. (Customers were informed that the design or detail work was being performed by student trainees, and the savings—in terms of lower-than-average salaries paid during the training period—were passed on to the customers in form of decreased design-room costs.)

The Singer Librascope trainees spent the worksite training portion of the program primarily doing detailer work on printed circuit board (PCB) designs. This included digitizing PCB drawings to input the design into the computer, editing existing designs, creating detailed drawings from an existing database, and creating photo tools. The students who completed their worksite training at JPL were given some design responsibilities as well as detail work. Their specific task was to work on mechanical designs for support equipment and peripheral structures, such as inspection platforms, for the Galileo spacecraft.

Given a basic design created by a JPL engineer, it was the trainees' job to complete the design, making sure that it met both the design and manufacturing standards (part tolerance and material selection, for example) specified by the design engineer. In many instances, completing the engineer's design required the trainee to design a part or structure forming a portion of the total design. The design work done by the trainees, closely monitored during the worksite training period, is a significant aspect of the duties of those trainees who became permanent employees.

Related Services: Counseling, Placement, and Follow-up.—Counseling, placement, and follow-up services were formally assigned to the college. The college's special projects department has a full-time counseling staff, one of whom was assigned part-time to the Coordinated Funding participants. In effect, however, most counseling was informal and was provided by the instructor and the Singer and JPublic Law employees who oversaw the students at the laboratory sites. Although placement services were officially the responsibility of the college, PIC representatives aided GCC in placing those program graduates who were not hired by either of the participating firms. Followup procedures, planned for 30-, 60-, and 90-day intervals after program completion, were conducted by the college.

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*The one student who did not pass the final exam was the only student who carried a full-time job while participating in the program. The combination of full-time work and program participation proved to be more than he could accommodate.

Results

Placement.—Seven of the 11 trainees who completed both the classroom instruction and worksite training portions of the program were hired by either JPL or Singer Librascope. JPL's stated intention at the beginning of the program was to train eight participants in its lab and to hire the four who were best qualified. The laboratory exceeded its original intention by hiring five trainees at the completion of the worksite training in February 1983. The new JPL CAD/CAM operators received entry-level salaries of $6 to $7.50 per hour. Two of the JPL trainees were placed in other firms in design and drafting jobs which do not, however, involve CAD/CAM operation.

Singer Librascope had originally intended to hire all three of the students who trained at the firm. One of them, however, failed to pass the security clearance required for all Singer Librascope employees. That trainee has since been hired by Glendale Community College in a nontraining-related capacity. The other two were hired by Singer in January 1983, at starting salaries of $6.25 to $7.25 an hour.

Singer hopes to hire four trainees from the second session of the program, which at this writing has not yet entered the worksite training stage. Whether or not JPL will be able to hire any of the second-session trainees will depend on the laboratory's need and funding situation at the end of the summer.

The Investment in People Project.—One of the results of the CAD/CAM operator program was achieved well before the first group of participants completed their classroom instruction. In October 1982, the State Community College Chancellor's Office and the EDD announced that additional funds for innovative college programs would be available under the Governor's Investment in People Initiative. Glendale Community College, again with the help of PIC and the City of Glendale, submitted a proposal to expand the CAD/CAM operators' program to adapt it to a wider range of applications (including architectural, piping, and structural design); to recruit additional applicants and involve more local industry; and to provide further training for instructors from GCC to help the college expand its already developed CAD curriculum.

In December 1982, the college was awarded Investment in People funding totaling $55,885 to provide 10 weeks of combined classroom instruction at GCC and onsite laboratory work at the Electro Optic Systems Division of Xerox Corp. and Jacobs Engineering (an architectural and civil engineering firm).

Unlike the Coordinated Funding Project participants, 32 of the 40 Investment in People participants were company employees requiring upgrade training in computer-aided design. Because the Xerox Electro Optical Systems employees were to be trained for aerospace applications, a combined class serving the second-session Coordinated Funding participants and the Xerox Investment in People participants was planned for the winter-spring semester of 1983. The Jacobs employees, who were to be trained in architectural applications, attended a separate course, taught by an employee of Jacobs certified by Glendale College. All of the industry employees received laboratory training at their respective companies. The eight trainees who were not company employees joined the Coordinated Funding participants at Singer and JPL.

Benefits.—Aside from the obvious benefits to the trainees, the CAD/CAM Operator Training Program produced beneficial results for the sponsoring companies, agencies, and institutions. Both employers got CAD/CAM operators trained in their specific applications and operations for a fraction of the cost involved in company-operated training programs. Singer Librascope, which specifically seeks young, energetic drafters to be trained as detailers in computer-aided PCB applications, obtained young CAD operators whose laboratory training was closely monitored by company employees—thus providing the assurance that they were trained in a manner acceptable to the firm. As added benefits, Singer representatives also point to their participation in the selection of the trainees and the opportunity to observe them over an extended period of time.

JPL representatives look on the training program as a first step in reducing the laboratory's dependence on the contract drafting houses that traditionally performed the manual drafting function now being replaced by CAD/CAM. According to the manager of the Design and Mechanical Support Section, the section has been able to accommodate double its previous workload since the introduction of the CAD systems in 1981 and can accomplish much of the work done by the contract drafters with a smaller number of permanently employed CAD/CAM operators. Furthermore, since the systems themselves are extremely accurate tools, JPL can increase productivity and lower its price structure by hiring trained CAD/CAM operators at entry-level salaries and passing the savings along to its customers.

An added benefit from JPL's point of view is the future potential of the trainees. All of those who were hired by JPL accepted their positions with the understanding that they will continue their education by pursuing 4-year engineering degrees and eventually become part of the engineering design staff in the section. In this way, JPL hopes to achieve a number of long-term results: to prevent the CAD/CAM operators from becoming static; to "home grow" new engineers who will have a working knowledge of CAD/CAM operations and JPL requirements; and to keep a constant flow of new CAD/CAM operators coming into the laboratory by replacing the older operators who have moved up to engineering design positions.

Glendale Community College, by obtaining the Coordinated Funding and Investment in People grants, now has increased credibility at the State level, which may, in turn, help the school to obtain additional funding for further innovative programs. Of equal importance is the CAD/CAM experience gained by the drafting instructor during his summer-long upgrading program, which was reinforced by his delivery of the academic-year program. In addition, the college got the opportunity to integrate computer-aided design into its regular drafting curriculum—an opportunity that would have been greatly delayed had GCC been forced to wait until it could obtain its own equipment.

Benefits to the Private Industry Council and Computervision were less tangible, but were, nevertheless, significant. By acting as the broker bringing the major players together and developing the operating systems that helped the program to succeed, PIC demonstrated that it could fill the needs of the community at large while, at the same time, setting the stage for a PIC-funded program preparing disadvantaged residents to become drafters who could then take advantage of training programs concentrating on CAD/CAM skills.

The program also aided the Private Industry Council by reinforcing the PIC-built bridges between the college and local industries and by demonstrating the PIC philosophy in action, i.e., that industrial commitment and academic training resources can be combined to benefit industries, schools, and potential employees. Computervision, by participating in a program sponsored by JPL and Singer, demonstrated its willingness to support its customers in an innovative endeavor while also helping to provide those customers with trained Computervision operators.

Problems/Solutions.—The necessity of condensing the Computervision courses to fit the time frame of the college semester and the need to separate the classroom and laboratory segments presented ongoing problems. Although the Glendale students did have 12 weeks to complete four 1-week Computervision courses, students who attend courses at one of Computervision's customer training centers engage in intensive 8-hour-a-day classroom and laboratory work. In the case of the mechanical design and printed circuit courses, the Glendale students received almost as much terminal time as a regular Computervision customer; but in the case of the introduction to CADDS 3 operation course, the coverage was reduced from approximately 40 hours to 10.

It should also be noted that Computervision recommends that its customers' employees have from 60 hours of terminal time (for detailers) to 120 hours (for designers) after they take the basic mechanical design course to thoroughly familiarize them with the system before they proceed to advanced mechanical design. This, of course, was impossible for the Glendale students, who, because of time constraints imposed by the 12-week semester, had to proceed directly from the basic to the advanced course.

While the first group of students did not feel that the classroom/laboratory schedule was inconvenient, the students who are attending the second cycle of the course do have a problem in that regard. Those who do their laboratory work at Singer Librascope must attend labs from 11:00 p.m. to 2:00 a.m. because the systems are in constant use for production purposes during the first two shifts. This presents obvious difficulties for the second-cycle students but alleviates the problem noted by Singer employees during the first cycle of the program, when regular employees were occasionally forced to work overtime in order to make up for the periods during which the terminals were used for training purposes. A similar problem was mentioned by some JPL employees, who had been accustomed to use the terminals "dedicated" to training for production design work.

A final problem related to the course structure is that the instructor occasionally had difficulty filling the mandatory 6 hours a week of lecture time with constructive material. While the chalkboard demonstrations of terminal operations and the pen-and-paper exercises were helpful to some extent, the instructor now feels that 4 hours a week of lecture and 8 hours of terminal time would be more appropriate for a course of this type.

While the instructor found ways to address some of the above-mentioned problems in the second cycle of the program, others were less amenable to immediate solution. The 10 hours originally devoted to the basic operations segment has been expanded to 20 hours. To deal with the problem of excessive classroom time, the instructor has assigned a term project for the second cycle of trainees.

As part of the project, students will write papers dealing with the advantages and disadvantages of various CAD/CAM systems for specific types of design work, such as mechanical, printed circuit board, architectural and piping. Each student is assigned an in-depth research project on a specific system for a specific type of application, and the instructor has arranged for more field trips to enable the students to see different systems in operation. At the end of the course, the students will make class presentations on the results of their research, so that the entire class will have some familiarity with a wide variety of systems and applications. Because both cycles of the course were firmly locked in to the college's schedule by the time the difficulties associated with the classroom/laboratory ratio became apparent, it was not possible to make the adjustment to the 4-hour lecture/8-hour lab format which the instructor believes would be the best long-term solution to this problem.

Lack of adequate periods of time for terminal practice between the basic and advanced mechanical design segments is a problem which as yet has no solution in a course which is structured to fit into an academic semester. Even if the college had a well-equipped laboratory dedicated to training, it is unlikely that the students could have logged in 60 to 120 hours of terminal time to fully acquaint themselves with the system before proceeding from the basic to the advanced segments of the course. It should be noted, however, that the students did have the opportunity to work on the terminals for at least 20 hours a week during the worksite training portion of the program. Therefore, although they may not have been able to make use of the terminals at the optimum period in the learning process, they did have up to 200 hours of experience on the terminals in addition to the time spent in the laboratory sections of the formal course.

A final problem, one noted by Singer representatives and by the Glendale instructor himself, is that—while the summer-long upgrading course provided the instructor with a grounding in the Computervision courses he adapted for his own course and a familiarity with the work of the Singer and JPL departments the students would be working in—his training was "barely adequate" to the task of training the students in advanced techniques. The major difficulty here was not with the abilities of the instructor, who had years of experience as an industrial designer and a drafting teacher and is familiar with the operation of another CAD/CAM system. However, while he was evaluated by both Singer and JPL representatives to be fully competent in his field and an excellent teacher, he did not have enough "system time" on Computervision terminals to become thoroughly familiar with all of the operations required for both mechanical and PCB design.

This problem has decreased as the instructor has had more opportunity to work on the system himself and to observe the types of difficulties his students run into on the terminals, and it can reasonably be expected to be overcome entirely with time and experience. Because JPL and Singer designers were always on hand to aid the students with difficult problems, the students did not suffer because of the instructor's lack of extensive production experience on the system.

Evaluation of Present and Future Capacity

In spite of the problems noted in the previous sections, the CAD/CAM operator training program can be rated as an overall success. The two employers have gained trained employees who fill what they both term as a "void" in their occupational structure, and both Singer and JPL pronounce themselves to be very pleased with the program graduates they have hired. The majority of the other graduates have obtained jobs; the college has gained experience in teaching a CAD/CAM course and hopes to be able to integrate it into its regular curriculum; and the Private Industry Council has strengthened its position as a "broker" between industry, academia, and those in need of training and jobs.

Many of the problems cited, are in fact, are normal "startup" difficulties associated with the initial implementation of demonstration programs with limited development time-frames. The other problems—specifically those involved in coordinating the resources and schedules of the industries, on the one hand, and the college, on the other—are currently being addressed by PIC and the college and require both long-range planning and flexible short-term adjustments to achieve a workable solution (see below).

Perhaps more important than the program's success in meeting its stated goals, however, is its value in demonstrating that industries and educational institutions can work together to meet their individual needs and the needs of the community with mutually satisfactory results. The present and future potential for the cooperative endeavor in high-technology training initiated by the college CAD/CAM program and its sister high school program, along with student and employer evaluations of the first cycle of the college program, are discussed in the following paragraphs.

Employer Evaluations.—Many of the employers' reactions to the program and to the students have been touched on in previous sections of this study. This section summarizes and draws together the overall response of the two employers who participated as major sponsors of the program.

Singer Librascope.—Singer representatives interviewed—the manager of engineering and planning, the supervisor of the computer-aided design department who oversaw the laboratory portion of the formal course and the worksite training, and a PCB designer who worked closely with the students during the worksite training—all believe that the trainees did "a great job" and are fully satisfied with the work and motivation of the two trainees who were eventually hired. Even though the third trainee could not be hired for security reasons, the Singer employees said that he, too, did "very good work" and that they would have hired him had he been able to pass the security clearance.

The supervisor of computer-aided design was extremely direct in both his praise and his criticism of various aspects of the program. He felt that the problem created for Singer in the case of the trainee who was unable to get a security clearance could have been avoided if more time and effort had gone into the initial screening process. The classroom training, in his opinion, was "adequate" but could have been "more adequate" if the Glendale instructor had received a longer training course himself. His final criticism of the program was that, while the trainees got a good "basic taste" of CADDS 3 techniques, the instruction would have served Singer's purposes better had it been "more focused" on printed circuit board design.

On the other hand, he recognized the instructor's problem of having students who would eventually be working in two different applications (mechanical and PCB) in the same class and believes that some grounding in mechanical design techniques is necessary for PCB detailers.

Overcoming all of his criticism of the program, however, was the fact that the two trainees who were hired were, first of all, precisely the type of employees he was seeking (young, intelligent, and highly motivated) and, secondly, were tailor-trained to meet Singer's specifications. The program was especially valuable from Singer's point of view in that it trained students who had drafting experience but who did not have previous computer-aided design experience; they therefore did not have to "unlearn improper or unprofessional techniques" or techniques specific to another industry or another CAD/CAM system. Six of the trainees in the second cycle of the program are now receiving laboratory training at Singer Librascope, and the CAD supervisor hopes to hire four of them.

Jet Propulsion Laboratory.—Representatives interviewed included the manager of the design and mechanical support section and the technical group supervisor for computer-aided design. Because the CAD/CAM operator training program was conceived and fostered by PIC (which is chaired by the JPL section manager), JPL's evaluation may be partially perceived as a parent's report of his child's progress. On the other hand, the section manager, being very much a businessman as well as a scientist, is committed to seeing a return on his investment in the trainees, and to hiring employees whose work meets the standards of precision required in the aerospace industry.

Another factor to be considered in JPL's evaluation is its philosophy of community participation and its approach to employee training. The Jet Propulsion Laboratory is the largest employer in the Glendale area, and its managerial employees have implemented their sense of commitment to the community by serving on the board of education, educational task forces, and organizations like the Private Industry Council.

JPL's participation in the CAD/CAM training program, therefore, was motivated not only by its need for trained operators but by its desire to increase the college's focus on high-technology training so that the school could better serve the needs of both the industrial community and the residents of Glendale. Integral to this approach is the notion that industry should communicate its perspective to educational institutions and work with them to address educational needs.*

Aside from attempting to strengthen industry-education linkages in the community at large, the design and mechanical support section manager has institutionalized upgrade training for all of the employees in his section. Forty hours a year of upgrade training for each employee is built into the cost structure of the section, and completion of that training is an important factor in each employee's yearly appraisal. This procedure, which is in essence a mandate that every employee continually upgrade his or her skills, was instituted at approximately the same time that the CAD/CAM equipment was installed in the section and grows out of the manager's perception of the need for engineers and support personnel to keep up with the dynamic advances of the computer-aided tools of their profession.

The JPL representatives who participated in the selection of the trainees for the CAD/CAM operator program therefore looked for applicants who were highly motivated and indicated a desire to continue their education; and the five trainees hired by JPL were those whose motivation both to work at the lab and to continue their education was most apparent. As noted previously, JPL sought trainees who would eventually become fully fledged design engineers—whom the training would provide with sophisticated entry-level skills and who had potential for career growth.

When interviewed halfway through the worksite training period, JPL representatives were well-satisfied with the work, the motivation, and the potential for success of all eight trainees. At the end of the worksite training, the five trainees with the strongest desire to pursue engineering degrees were hired. Two months after they were hired as full-time employees, they were, according to the section's CAD supervisor, "doing very well" and continued to be enthusiastic and motivated. Ten trainees in the second cycle are now receiving laboratory training at JPL (eight from the Coordinated Funding Project and two funded by Investment in People).

Student Evaluations.—Individual interviews were held with five session I graduates—the two graduates hired by Singer Librascope and three of those hired by JPL. The students were uniformly positive about the instructor, appreciative of the experience they had received, and enthusiastic about the current work. All of the students gave the instructor an excellent rating, and some added that he was one of the best teachers they had ever worked with. They specifically noted his ability to provide clear and concise explanations; his attention to detail; his willingness to provide personalized assistance; and his patience and dedication.

While all of the students rated the course content highly, the new Singer hires would have preferred more class- and laboratory-time devoted to printed circuit board design. The other problem—one mentioned by the instructor himself and all of the students interviewed —was the ratio of classroom to laboratory time. While most of the students found the 6 hours of lecture per week helpful in the beginning of the course, all stated that more lab and less lecture would have been more appropriate during the second half. Two students noted that the small size of the class resulted in specific benefits: personalized instruction and an environment that encouraged the students to help each other to explore a variety of design techniques. Others mentioned that the instructional material, especially the Computervision workbook, were excellent and that the class projects were especially helpful as learning experiences.

Although many of the students were required to travel long distances—both to the college from their homes and between the college and the laboratory sites—only one mentioned traveling as a problem. None of the students felt that the timelag between the classroom lectures and the laboratory practice sessions created undue difficulties. All of the graduates stated that the laboratory experience was the most beneficial aspect of the program—not because the lectures were not good, but because of the necessity to engage in hands-on practice on the equipment. Two of the JPL students specifically mentioned the helpfulness of JPL employees during the laboratory sessions.

When, however, the students were asked if they preferred the college-classroom/industry-lab-site set-up to a situation in which the lectures and laboratory work could have been centralized in one location, all but one said that it would have been preferable that the equipment be located at the college. The dissenting student (one of the few who had not had previous industrial experience) said that the industrial environment provided him with a greater incentive to work harder and learn more than would have been possible in a classroom environment. All of the students, on the other hand, felt that the 7 to 10 weeks of worksite experience after the formal coursework was extremely valuable, primarily because they were given "real" work rather than make-work and because it gave them an opportunity to learn about the specific working procedures of the two industrial laboratories.

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*JPL, which is an outgrowth of an educational institution but which operates like a company, is perhaps uniquely structured to create the academic-industry linkages illustrated by the CAD/CAD program.

All of the students expressed their intention of continuing their education at 4-year colleges or universities. One plans to pursue a mechanical engineering degree, and the others intend to work on degrees in industrial design.

Present and Future CAD/CAM Training Capacity of Glendale Community College.—At the completion of the first cycle of the CAD/CAM program, Glendale College, as the program operator, had met most of the objectives set out by the Coordinated Funding sponsors. The college, with the help of PIC and the sponsoring companies, had operated a vocational training program that met the needs of specific local employers; had involved the employers and "other appropriate entities" (PIC and Computervision) in planning, design, and implementation; and had provided the participants with effective job skills training and continuing employment with career advancement potential. The final objective of the Coordinated Funding Project—to incorporate the resulting curriculum into ongoing college vocational education programs—has proved to be more difficult to accomplish.

Operating a program combining classroom and worksite training produced a number of beneficial results, not the least of which were the availability of state-of-the-art equipment at the industry sites and the opportunity given to the trainees to acclimate themselves to an industrial environment. The use of industrial labs and the instructor upgrade training provided by project funds enabled the college to demonstrate its effectiveness in training vocational education students to meet industrial needs. The expansion of the program under Investment in People funding also demonstrated that the college could serve as a resource for training existing industrial employees as well as entry-level candidates.

The college, however, is painfully aware of the possible "self-destructing" nature of a CAD/CAM program operated by a school with no equipment of its own. By the end of the second cycle of the program, both Singer Librascope and JPL will be "saturated" with CAD/CAM operators, at least for the present. In order to keep the program running, and to truly incorporate it into the ongoing curriculum of the college, GCC will have to find other sources of equipment.

This potential problem was apparent from the inception of the program, and both PIC and the college's director for special projects have been actively working on a solution. College representatives believe that the least promising solution in the long run is to assume that they will be able to perpetuate the program indefinitely by relying completely on industry laboratories for the hands-on portion of the training. They are, consequently, exploring the possibility of obtaining donated or reduced-price equipment to be installed at the college to be used for the training of regularly enrolled drafting and design students and for operating upgrade programs for industry.*

Technical Training Center.—Another possibility, one which now looks extremely promising, is the creation of a centrally located technical training center, supported by local industries, schools, and agencies and outfitted with equipment to address a wide variety of "high tech" skills including CAD/CAM, computer repair, and word processing. The center—which until recently was little more than an idea conceived of by the chairman of the Private Industry Council—is now beginning to look like it may become a reality.

A recently closed junior high school in Glendale would provide the site; education and business leaders and local government officials have informally agreed on the concept; and a major producer of CAD/CAM equipment has expressed interest in the possibility of donating equipment. The current thought is that the facilities would be shared by all of the schools in the district and would operate on a three-shift schedule, allowing for three, 3½-hour teaching units in each subject per day. Although such a center would be challenging to administer and maintain, and although students would still have to travel to laboratory sessions, the problems noted previously with regard to coordinating production and training use of industry equipment would be solved, and the college would have access to the equipment it needs to continue its CAD/CAM course and to expand into related areas.

Future Potential.—Glendale College vocational education instructors and administrators believe that a crucial element in the college's future potential to operate vocational education programs is the maintenance and expansion of the communication channel with local industries, established through such means as the school's association with PIC and the Coordinated Funding and Investment in People projects.

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*In mid-May 1983, the college made the decision to continue the CAD/CAM training program through June 1984, funded with regular district funds. The lecture portion will remain at the college. The lab work will be conducted in the private sector at late night and early morning hours. In addition, the college administration is now developing a foundation which will be able to borrow money to be used, in part, to build new laboratories to house the equipment and to cover equipment maintenance costs.

The open channel to industry representatives is seen as necessary for a variety of reasons. Glendale representatives believe that colleges are 5 to 10 years behind industry in technical expertise and sophistication of equipment; and they look on industry as a resource for instructor upgrading, information about new industrial advances and hiring requirements, and material and equipment to implement new courses.

The college drafting instructor, for example, believes that within the next few years mechanical and architectural drafting programs that do not incorporate computer-aided design will not be achieving their major goal, which is to produce job-ready graduates. In return for industry support, the vocational education division of the college is committed to institute whatever ongoing changes are reasonable and necessary to meet industrial needs and to serve as a training resource for local industries.

Although the college's present capacity to teach programs in computer-aided design and manufacturing is limited by its almost complete lack of equipment, the bridge-building activities of the past 4 years (participation in PIC programs and representation on the PIC board, recruitment of industrial representatives for college advisory committees, and participation in programs like the Coordinated Funding Project) seem destined to bear fruit in the near future. Local industries that have benefited from CETA training programs operated by the college now donate material, equipment, and funds. The success of the Coordinated Funding Project demonstrated the college's ability and may bring more industrial support, open more industrial labs, and help the school to win more State funds.

The Investment in People grant, which allowed the school to expand the CAD/CAM operator program, is but one example of the college's potential to build on the achievements gained through working with local industries and agencies. More recently, the college was chosen as one of the possible west coast sites for the General Motors/United Auto Workers retraining projects. The program proposed by GCC—a year-long electronics technician course—has been accepted in concept and will be implemented if it proves feasible for 20-laid off GM workers to either relocate to or travel to Glendale for the length of time it would take to complete the course.

The synergistic relationship between the college, the Private Industry Council, and the City of Glendale is a major key to the college's future potential. PIC has engaged the support of its board members to aid the college in obtaining equipment. This, in itself, becomes a very powerful resource because of the stature of the industries—including JPL, ITT, Pacific Telephone, and banking and financial organizations—represented on the PIC board. Whether the final result of the effort to build GCC's equipment and laboratory resources takes the shape of a training center to which the college has access, or laboratories located on the college campus, the partners in the school-city-PIC relationship seem committed to making use of whatever equipment is obtained to serve the broadest possible constituency.

The Glendale Private Industry Council.—While the formal role played by PIC in the operation of the CAD/CAM operator program was relatively minor, the importance of the Private Industry Council as an informal broker between educational, industrial, and governmental organizations cannot be overestimated. The idea for the CAD/CAM operator program originated with the PIC director and chairman; the PIC chair secured the cooperation of his own organization (JPL); the PIC director enlisted Singer Librascope and Computervision; and the PIC staff assisted in placing the cycle I graduates who were not hired by the participating firms.

Although PIC's formal mandate is to operate training programs for structurally unemployed and displaced workers, the philosophy of the Glendale council encompasses a much wider sphere of activity than the direct operation of government-funded training and employment programs. Integral to that philosophy is the creation of linkages between the industrial and educational committees to enhance the activities and resources of each and to serve the community as a whole.

In light of this philosophy, the role of the broker is profound, especially when one considers the difficulty of creating matches between the two ends of the labor market spectrum: on one end, technologically oriented industries requiring many workers to have ever-more sophisticated entry-level skills; and, on the other end, the structurally unemployed,* who may have few workplace skills, and displaced workers, who may be only semiskilled.

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*Structurally unemployed individuals are those whose situation reflects long-term changes in economic conditions, in contrast to the "cyclically unemployed" who are periodically without work due to short-term changes in the general economy.

Occupying the vast middle ground are colleges and high schools requiring assistance to update their curricula and upgrade their instructors so they can assist in the job training process; workers with outdated skills who do not meet the Federal poverty guidelines and are therefore ineligible for federally funded programs; and firms whose workers require upgrade training but which may not have the resources to provide that training inhouse. By taking the broad approach and making the most of its formal and informal channels of communication between all of the sectors of the community, PIC hopes to have a pervasive effect which, in the long run, may create that match between industry's high-tech needs and the structurally unemployed.

At present, PIC is working on a number of fronts, which, when brought together, may enable it simultaneously to serve the needs of high-tech industries and the structurally unemployed. Although the CAD/CAM operator program did not serve the structurally unemployed, it did serve some displaced workers and some who were below the poverty level. It also strengthened the college's training capacity and aided local industries. In addition, the CAD/CAM program demonstrated the feasibility of bringing the various participants together to create a successful high-technology training program and set the mechanism in place for expanding it.

This type of activity—working both formally and informally to strengthen various segments of the education and training system and concentrating on strengthening the links between the segments—illustrates another tenet of the Glendale PIC philosophy, characterized by the following statement by the PIC chair: "There's a need to recognize that nothing is static—once you get into it, you've got to be willing to move. The way we've done that is to address needs that are peculiar and particular to industry now, and we ask industry to forecast needs downstream, so we can be ready to alter our training programs to be ready at the time that the need exists. My impression is that industry loves it if they're included and that school systems are now put in the position of preparing students for the real world. They're beginning to realize that they're both part of it and that the responsibility is a shared one."

To further strengthen education's knowledge of industry, PIC is working to encourage local schools to substitute a work experience program for the traditional sabbatical leave for instructors and to provide appropriate promotion credits for such a program. To increase industry's recognition of the capacities of educational institutions, PIC encourages companies to look on vocational education teachers as a training resource and to contract out in-house training to the colleges.*

This system, according to the PIC chair, would cost the companies less than in-house training and would strengthen the schools' capacity to provide industrial-level technical training. While this notion would not necessarily work for all types of training in all companies, it is likely to work in a number of instances if well-managed and properly designed.

The CAD/CAM operator program illustrates that industry-education cooperative training endeavors can succeed, in spite of the difficulties that inevitably occur. The problem now facing Glendale Community College—how to continue the course when the two industrial sponsors are saturated and the equipment question is still up in the air—graphically illustrates the PIC chair's statement that "nothing is static." PIC and the college, however, are ready to move—either to move to other companies to keep the program running until a permanent solution can be found, or to acquire equipment or establish a training center. This type of innovative approach to CAD/CAM training, which relies on mutual cooperation while recognizing that circumstances change and resources are limited, may not be guaranteed of certain success, but it is most certainly well worth the attempt.

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*In many cases, this would involve providing industrial upgrade training to the teachers, as was done in the case of the GCC instructor.

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Office of Technology Assessment

The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts that can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

Requests for studies are made by chairmen of standing committees of the House of Representatives or Senate; by the Technology Assessment Board, the governing body of OTA; or by the Director of OTA in consultation with the Board.

The Technology Assessment Board is composed of six members of the House, six members of the Senate, and the OTA Director, who is a nonvoting member.

OTA has studies under way in nine program areas: energy and materials; industry, technology, and employment; international security and commerce; biological applications; food and renewable resources; health; communication and information technologies; oceans and environment; and science, transportation, and innovation.

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